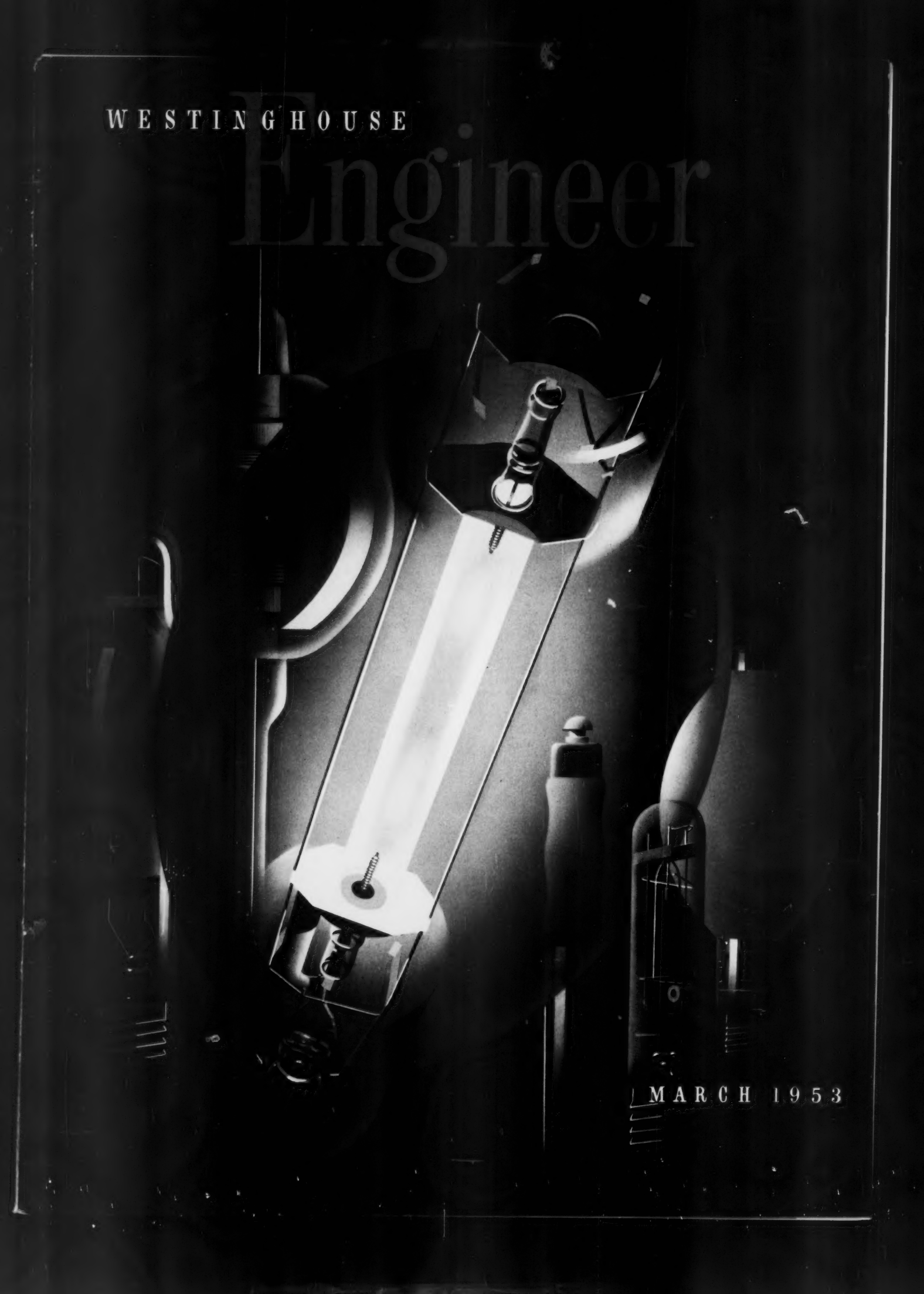
WESTINGHOUSE

# Engineer



MARCH 1953

# Phosphors—

## USEFUL, TEMPERAMENTAL, MYSTERIOUS STRANGERS

Twenty-five years ago relatively little was known about the phenomenon of fluorescence. Comparatively few cared. Today it is the basis of multi-million-dollar industries. Phosphors are essential, of course, to fluorescent lamps, produced by the million yearly. Without phosphors black-and-white television of today would not exist; on them the color-television industry of tomorrow will be likewise dependent. Phosphors are essential to the cathode-ray tubes required by every laboratory, and to the fluoroscopic screens equally essential to the medical profession. Then there are the fluorescent paints used on highway center safety strips, night traffic markers, billboards, and for theater effects—to mention but a few.

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Ask a physicist what makes a phosphor tick and he will tell you that if certain crystalline compounds are energized in any one of many ways, some electrons in the outer shells of the atoms are driven out of their normal position. In doing so they have absorbed energy, just as does a kicked football.

When those electrons return to their normal positions they re-emit that energy, mostly in the form of radiation (visible or invisible). The phosphor luminesces. The way in which each phosphor does this is characteristic of it; its spectrum is as unique as a fingerprint or the pattern of a snowflake.

If the electrons return to their normal positions directly and immediately after the excitation ceases—i.e., in about one hundred millionth of a second ($10^{-8}$ second)—the luminescence is the type called fluorescence, which is light with no persistence. The term was derived from this observable property of the mineral fluorspar.

But electrons do not always do this the simple way. Instead of falling back "home" directly, an electron may fall to a "trapping" state just below the so-called "conduction zone." It cannot, usually from this position, fall back into its normal position. It is trapped until it receives further energy that lifts it out again to the conduction band, from whence it may return to its natural location directly or repeat the intermediate step perhaps many times.

In any case the light emission is delayed by some period greater than $10^{-8}$ second, which is the time required for an electron to move from one level to another if it does so directly. The delay (i.e., persistence) may be a day or so. Thus we have phosphorescence, after which phosphorus was incorrectly named. (The visible glow of phosphorus in moist air is a chemical action, i.e., chemiluminescence.) Phosphorescence is a physical action and is predicated on no chemical reaction, although most phosphors under long-continued excitation do undergo a slow chemical change or deterioration.

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Few subjects in the physical world are more complex than phosphors. We can, here, do little more than suggest the extent of this complexity. In the first place tens of thousands of phosphors have already been catalogued. The potential number is astronomical. Physicists point out that most materials in nature are phosphors to a degree.

If it were a matter only of cataloguing all possible chemical compounds for luminescent properties the chore would be sizable—but not impossible. But other factors compound this many, many times over.

• • •

Contrary to what one might think, pure crystals do not generally make the best phosphors. Some "impurities" are necessary. And the kind and amount of impurities are highly critical. Take a simple phosphor, for example, like zinc sulphide. For this compound to luminesce, it is thought that some excess of (i.e., uncombined) zinc or sulphur must be present. Not very much—only a few parts per million. On the other hand, if the surplus is excessive, the effect is ruinous to the phosphor. But, still we don't have a good phosphor. An additional "impurity," called an activator, must be mixed with the crystalline compound, called the host. There are many possible activators. A recent textbook on the subject gives a partial list totaling 41, each being an activator for many known phosphors. Manganese is one of the most widely used. This same text lists 120 compounds for which manganese is an activator. In each case the permissible amount of the activator is small. Some activators are used in a few parts per million, others several hundred parts per million, but in almost all cases the allowable limits are narrow. A little too much and the activator becomes a poison. In fact some elements are activators for certain hosts, but for others they are poisons even if present in minute amounts.

Then, to complicate matters further, sometimes two activators are necessary. Neither, alone, will do the trick. It is as though one activator is required to make the other effective. Why? The physicists wish they had the answer.

Phosphors can be excited in many ways: by ultraviolet radiation as in fluorescent lamps, by x-rays as in fluoroscopic screens, by electron beams as in cathode-ray tubes, by neutrons as in nuclear-radiation detectors, and by electric fields as in electroluminescence. There are others. Most phosphors can be excited by some of these methods but not by all. For some phosphors the manner of excitation has a bearing on the spectrum of emitted radiation or light. It is enough, however, that it must be taken into account. Each of the multitude of phosphors must therefore be investigated to determine its behavior under several different classes of radiations.

Ambient temperature is another complicating factor. Most known phosphors work best at room temperatures or a little above, but lose efficiency rapidly at higher temperatures. But, illustrative of the queer quirks of phosphors, this is not always so. Some are most effective when operating at several hundred degrees C, which, indeed, is what makes the fluorescent-mercury lamp possible. (See p. 50.) And, again to show the contrariness of these crystals, some phosphors do their best work at extreme cold, say, liquid-air temperatures.

Obviously the possible combinations are virtually endless. The size of the research job is staggering. As matters stand at present, physicists have theories as to what is happening in the crystals. However, no one can yet predict, from fundamental considerations, what a hypothetical phosphor will do. Each combination of crystals, activators, excitations, and other factors must be individually explored.

• • •

The subject of phosphors combines great versatility with great complexity and mystery. E. G. F. Arnott (of whom there is more on p. 58) sums up the matter well: "We have learned a great deal about how to use phosphors but relatively little about how to use them efficiently (except in fluorescent lamps), and much less about how they work."

• • •

To research men this situation is intolerable. They are determined that this will not always be so and are making an intensive effort to that end. When they succeed we will have not only better phosphors for their many useful functions, but also we will know a great deal more about the fundamental structure of matter comprising the world around us.

WESTINGHOUSE Engineer

VOLUME THIRTEEN MARCH, 1953 NUMBER TWO

## On the Side

*The Cover*—A whole family of lamps for many different uses has evolved from the arc discharge through mercury vapor. It is this array of mercury lamps that artist Dick Marsh has portrayed on this month's cover, as a background for the basic ingredient of all the lamps—the mercury arc itself.

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Some may notice that a change appears in the advisory committee for the Westinghouse ENGINEER, listed at the bottom of this column. The newcomers are A. C. Monteith, Vice President in Charge of Engineering, and J. H. Jewell, Vice President of Sales. These men replace R. C. Bergvall and W. W. Sproul. This change recognizes shifts in Westinghouse organization and consequent shifts in responsibilities that have occurred in the last few years.

The change, we are glad to report, means no lessened interest in the fortunes of the Westinghouse ENGINEER on the part of Messrs. Bergvall and Sproul. They assure us they will be as willing to listen to our editorial problems, to act as "sounding boards" for editorial ideas in the borning, and to criticize us when we err as before. To these men the editors gladly give much credit for helping to establish publication policies and for a large share of whatever success the publication has achieved.

Special mention should be made of Mr. Bergvall's participation on the advisory board. He has been a member since the founding of the publication in 1941 and hence had a sizable and most beneficial hand in laying the basic policies still being followed without major change.

The Editors

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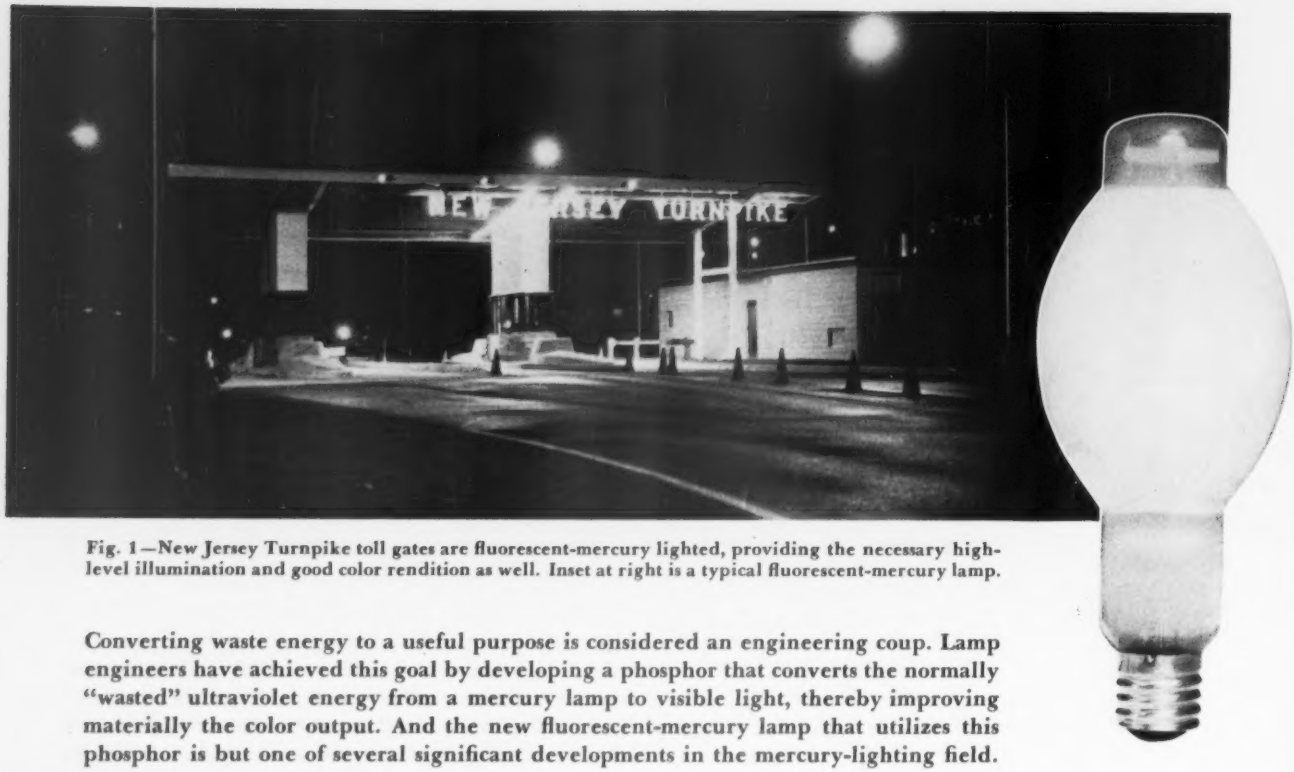


Fig. 1—New Jersey Turnpike toll gates are fluorescent-mercury lighted, providing the necessary high-level illumination and good color rendition as well. Inset at right is a typical fluorescent-mercury lamp.

**Converting waste energy to a useful purpose is considered an engineering coup. Lamp engineers have achieved this goal by developing a phosphor that converts the normally "wasted" ultraviolet energy from a mercury lamp to visible light, thereby improving materially the color output. And the new fluorescent-mercury lamp that utilizes this phosphor is but one of several significant developments in the mercury-lighting field.**

# *Mercury Lighting*—Whiter, More Versatile

E. W. Beggs, *Commercial Engineering Dept., Lamp Division, Westinghouse Electric Corporation, Bloomfield, New Jersey*

The most important new light source since the birth of the fluorescent tube is the fluorescent-mercury lamp, introduced by Westinghouse in 1950. This is the mercury-vapor lamp that produces white light instead of blue-green, and relieves mercury lighting of its historic color limitation.

The new fluorescent-mercury lamp, besides making the mercury type acceptable for all big lighting needs, also has proved to be the most economical and convenient light source for mass white light ever devised. In the history of mercury sources, this achievement possibly exceeds in importance the development of the 400-watt A-H1, the first single-ended mercury lamp, introduced in 1934. Before that there were the Cooper-Hewitt lamp, the first practical mercury lamp sponsored by Peter Cooper-Hewitt and George Westinghouse, and much earlier, experimental gas-discharge tubes by Davey, Faraday, and Geisler. The new "white mercury" lamp promises to revolutionize American lighting practice, particularly for large-scale operations, both indoors and out.

This development has, of course, been the result of the demands of American industry for lamps of higher efficiency, higher power, and longer economic and useful life. Early in the search for answers to these demands, lamp designers turned to vapor lamps because their inherent characteristics were favorable. Westinghouse, with Cooper-Hewitt, chose mercury-vapor mainly because of the high luminous efficiency available with the mercury discharge. Low-pressure lamps of 1910 showed promise, with efficiencies in the order of 18 lumens per watt contrasted with the 3 or 4 lumens per watt of carbon-filament lamps. Today, the 1000-watt mercury lamp has an efficiency of 55 lumens per watt and has an output of 55 000 lumens as compared to 21 800 lumens for a 1000-watt incandescent. The useful life of modern mercury lamps is many times that of comparable incandescent types, so for medium- and high-bay industrial installations, the mercury lamp has been pretty much king. Now, with the advent of the newest development—the fluorescent-mercury lamp—the mercury-type lamp may become almost universal in lighting.

### How It Makes White Light

The visible spectrum of mercury has four major lines or bands—the orange-yellow at 5770–5790 Angstroms, the yellow-green at 5461 A, the blue at 4358 A, and the violet at 4047 A. The ultraviolet spectrum of mercury contains many more lines. This entire spectrum can be controlled to some degree by governing the mercury-vapor pressure in the arc chamber. At a low pressure, such as 5 to 10 microns, the principal line in the ultraviolet is at 2537 A, which fact, incidentally, is put to good use in the bactericidal Sterilamp and in the conventional tubular fluorescent lamp. This wavelength is most effective in destroying certain types of bacteria and in exciting ordinary phosphors to fluorescence. The visible spectrum at low pressure is weak and is confined almost entirely to the four lines mentioned.

As vapor pressure is increased, however, the energy radiated

**Fig. 3—A cross-section of a fluorescent-mercury lamp, showing the arc tube.**

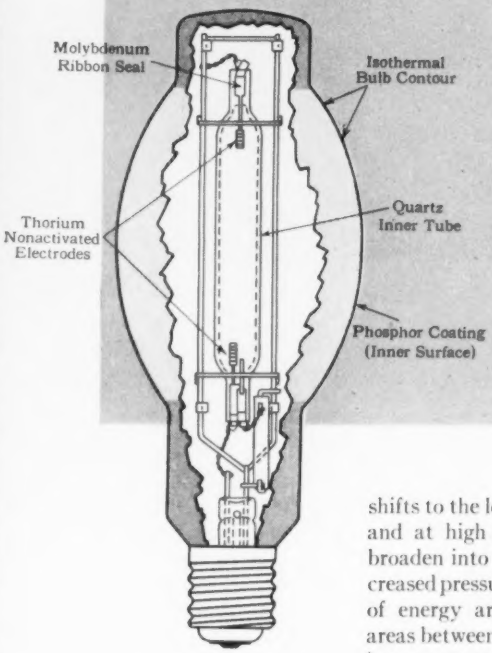
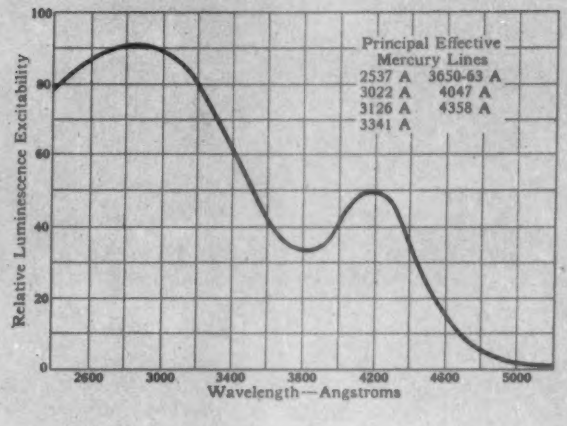



**Fig. 4—This shows that the phosphor magnesium fluorogermanate reacts to the entire ultraviolet spectrum of the mercury-vapor discharge and utilizes some energy at the violet end of the visible spectrum.**




shifts to the longer wavelengths, and at high pressure the lines broaden into bands. Also, at increased pressures, small amounts of energy are radiated in the areas between bands, thus creating a somewhat continuous spectrum and a more nearly white light. There is, of course, an economic and physical limit to the vapor pressures that can be used in mercury-vapor lamps.

Today's mercury-vapor lamps use a medium pressure of approximately three atmospheres. At this pressure, over half the total radiations lie in the ultraviolet. These ultraviolet radiations have been put to good use in the sun lamp, in "black light" for industrial inspection techniques and theatrical lighting, and in photochemistry, where the ultraviolet is used as a catalyst. Prior to the fluorescent-mercury lamp, however, this ultraviolet energy was not utilized to produce visible energy for illumination purposes.

The new lamp puts these previously wasted radiations to good lighting use because of two major developments: (1) the use of a quartz arc tube, coupled with the use of electrodes of thorium rather than of tungsten wire coated with metallic oxides, and (2) the coating of the inside of the outer glass envelope of the lamp with a special phosphor, magnesium fluorogermanate, which fluoresces red under ultraviolet.

### Quartz Arc Tubes

Mercury-lamp arc tubes were made of glass until 1936. The mercury-vapor pressure, and consequently the effectiveness of these lamps as light sources, was limited by the melting point of this glass. Furthermore, it absorbed ultraviolet rays. Considerable experimentation was done with quartz, which has a high melting point and high ultraviolet transmission properties. It was soon found that quartz was attacked by sputtering of emission mixtures from the so-called activated electrodes, which were then tungsten wire coated with barium, strontium, and calcium oxides. More research evolved a thorium electrode, which has no coating; this solved the emission-mixture problem and gave long life to quartz lamps.

Because quartz has a higher melting point, higher arc loadings are permissible. More watts per square inch of arc result in smaller, more brilliant, and more efficient light sources of better color quality. Quartz arc-tube lamps can also be operated in any position. The first lamp to have such an arc tube, the 400-watt E-H1, produces over 30 percent more lumens than its predecessor, the 400-watt A-H1, made with a hard-glass arc tube. This has led to extensive substitution of the E-H1 for the A-H1 in industrial lighting. Very important in the new fluorescent-mercury lamp, quartz has also made the entire ultraviolet spectrum available.

### The Phosphor

Theoretically, it was known that white light could be produced from mercury lamps by adding red to the blue-green light of the mercury arc. Furthermore, the technique of using ultraviolet energy to make a phosphor fluoresce has been used in fluorescent lamps for many years. Yet lamp designers have been slow to apply this technique to mercury lamps. Economical long-lived quartz lamps had to be developed first. Later, the stumbling block was the lack of a suitable phosphor.

The phosphor that can do the job has to fill a handful of

**Fig. 2—This high-bay factory installation is an ideal application of mercury lamps, particularly for 1000-watt sizes.**

**Fig. 5—Store fronts are ideal applications for fluorescent-mercury lamps. They give the high output provided by mercury lamps and more true rendition of color values.**

tough qualifications: (1) it should be as white as possible so that it does not subtract materially from the visible mercury emission; (2) it should respond efficiently to all wavelengths of the ultraviolet available from the arc; (3) it should possess this same kind of response at temperatures of 300 to 500 degrees C; (4) it should fluoresce in the spectral ranges where mercury is deficient, primarily the red; and (5) it should be thermally and photochemically stable at the temperatures and radiation densities encountered in quartz-mercury lamps.

Luke Thorington, working in the Westinghouse Lamp

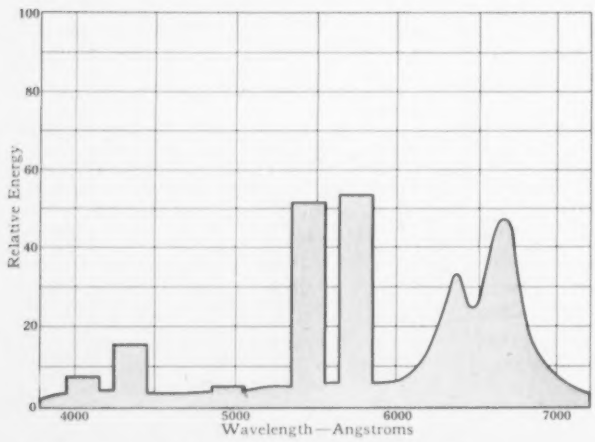



**Fig. 6—This shows the relative output of the fluorescent-mercury lamp. The rectangular bands are contributions from the mercury itself while the portion from 6000 to 7000 Angstroms is largely contributed by the phosphor.**

Research Laboratories, developed this somewhat incredible phosphor—magnesium fluorogermanate—and, hence, made white mercury light possible.

Magnesium fluorogermanate fluoresces a brilliant red under the entire ultraviolet spectrum from the visible out to 2000 A. The excitation efficiency, that is, the phosphor's response to ultraviolet radiations, is high throughout the entire ultraviolet spectrum. The conversion of the invisible ultraviolet light to red light results in a band of energy in the visible spectrum at 6000 to 7000 A. This produces a red light of high brilliance with most of the radiations in that part of the red band where the human eye is most sensitive.

This particular phosphor is almost snow white when viewed in white light. Because it has high reflection and transmission characteristics for all the visible light that strikes it, very little light is lost. It not only fluoresces efficiently at high temperatures but also actually reaches its peak of efficiency at 340 degrees C, which is the operating temperature of the outer bulb of the lamp on which the coating is placed.

### Types Available

The 400-watt mercury lamp has always been the size used in greatest numbers. Logically, it was the first fluorescent-mercury type developed. This lamp (J-H1) now has an average useful life in excess of 6000 hours. Its initial light output is 18 000 lumens, which is not far below that of a 1000-watt incandescent lamp at 21 800 lumens. It operates on standard auxiliaries and can be substituted for straight mercury lamps in any fixture that permits its slightly larger bulb to be seated in the lamp socket.

When replacing the older 400-watt straight mercury (A-H1) with the fluorescent-mercury, the color of the light is improved and the light output is increased 20 percent. When the fluorescent-mercury is substituted for the newer quartz-type straight mercury lamp (E-H1), there is a decrease of 10 percent in light output, but the glare factor is decreased and the color of the light is changed to white.

Incandescent lamps are often used in combination with straight mercury lamps to get the desired color. When these installations are changed to straight fluorescent mercury, the total number of lamp replacements required per year is drastically reduced due to the much longer life of the fluorescent-mercury. For example, in a combination incandescent and mercury installation of five hundred 750-watt incandescent and an equal number of 400-watt mercury lamps, the total number of renewals for a 4000-hour year would be approximately 2330 lamps. However, if a 400-watt fluorescent-mercury system were used throughout, only 670 lamps would have to be replaced in the same period.

In recent years, there has been a trend toward the use of the 1000-watt straight mercury lamp (A-H12) wherever a very high output unit can be used to reduce lighting costs. Lamp replacement is less costly with the larger lamps since fewer fixtures have to be installed and maintained and the larger sizes are relatively cheaper and more efficient. It was soon apparent that a 1000-watt fluorescent-mercury (C-H12) was needed. Because of its high output (50 000 lumens) and high efficiency the number of luminaires is reduced to a minimum and lighting costs are cut. Its best applications, of course, are large installations where lamps of very high power would normally be employed. The 1000-watt C-H12 is designed for 230-volt circuits and its new companion, the 1000-watt B-H15, is designed for the growing 480-volt systems. These two lamps are now the most economical sources of mass white light and will probably be the chief ones used for large-area lighting in the future.

## Application

Fluorescent-mercury lamps are finding their greatest application in installations where color discrimination is involved and where sources of high lumen output can be used. They are now being installed in large industrial areas such as airplane factories, erecting shops, fabricating and assembly areas, forges, foundries, and generator stations. They are being applied with great success to light railroad and airport terminal buildings, auditoriums, and sports arenas. In out-of-doors lighting, such as store fronts, service stations, parking lots, shipyards, construction areas, freight yards, and streets, these new lamps are often the most convenient as well as the most economical lamps to use.

Due to its relatively low brightness, the 400-watt fluorescent-mercury lamp is finding application at lower mounting heights than would be acceptable with straight mercury lamps. The minimum is approximately 18 feet for the straight mercury lamps in conventional equipment, but fluorescent-mercury lamps are being used successfully at 15 feet and less. Perhaps new lighting fixtures will be designed to shield the lamp and diffuse and distribute the light so that the mounting heights can be brought even lower. Inasmuch as a large part of lighting today is in lower ceiling areas, the fluorescent-mercury may be applied in areas strange to mercury lamps.

## Other Mercury Lamps

Some of the developments that made the fluorescent-mercury lamp possible have been used to good advantage in other lamps. Most important of these are more effective lamps for blueprinting and photochemistry, for black-light industrial inspection, for sunlamp home application, reflector lamps for industry, and an entirely new type—the short-arc lamp, which introduces mercury sources to entirely new fields.

### Reflector Lamp

The development of the practical quartz arc tube, for instance, has made possible a mercury reflector lamp with a reflector coated on the inner surface of the bulb itself.

Since quartz is able to withstand much higher temperatures than the hard glass formerly used, the quartz tube can be made much smaller. This fact has allowed lamp designers to install a tube in the ordinary reflector-lamp bulb.

The newest members of the reflector-lamp family are the 400-watt mercury medium-beam (L-H1) and the 400-watt mercury wide-beam (K-H1) lamps. Designed for general industrial lighting, they are particularly valuable in places where smoke, dust, and dirt deposit on lighting equipment. The reflector is sealed inside the glass bulb, so it stays clean.

### Short-Arc Lamps

The quartz arc tube has also been the chief factor in the development of the short-arc lamp. This provides a light source of extremely high brightness, which is achieved by shortening the length of the arc and increasing the wattage per unit of arc volume one-hundred fold. Naturally, the temperatures are greatly increased but, with proper design, the quartz resists the heat without air blast or water cooling.

The present applications of short-arc lamps are limited but promise to grow. They are now being used in certain photochemical processes and in searchlight-type units for cloud-height measurements at airports. They are being tried out in motion-picture studio lighting and in the field of photolithography. In optical projection and in marine and military searchlights, they fill the age-old desire for a bulb-type source.

With an ever unsatisfied need for more light and with the whole world—above and below ground, indoors and out—still relatively underlighted, only the boundaries of imagination limit the use of these new sources. For large areas, a mercury lamp cuts lighting costs to a minimum, so man can use them where other sources would be too costly. A fluorescent-mercury lamp now provides maximum convenience and lowest cost for mass white light, so together these two new types of lamps hasten the day when we can have enough light wherever and whenever we want it.

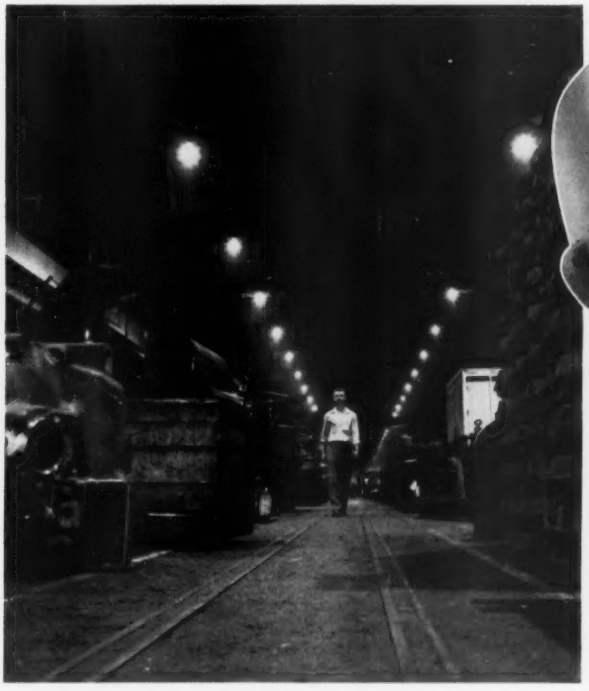


Fig. 7—The reflector-mercury lamp (above) and a typical installation.

Fig. 8—The distribution curves for the medium- and wide-beam reflector lamps.

# Applying the *Wound-*

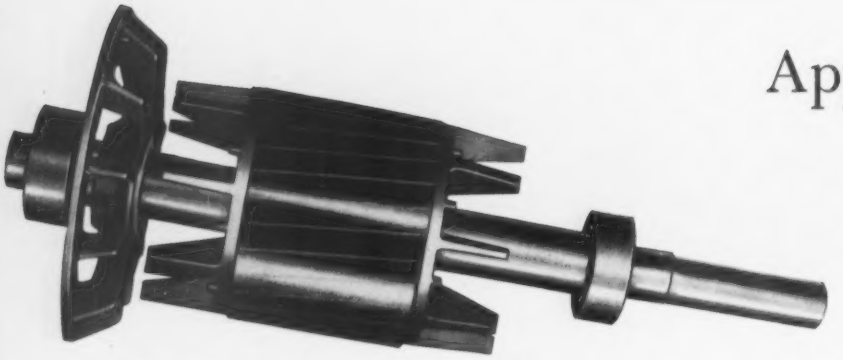


Fig. 1—This is a die-cast rotor for a squirrel-cage motor.

**The wound-rotor motor is in much the same position as a man with a famous brother. Its kin, the squirrel-cage motor, has long been a favorite with industry, because of its ruggedness, simplicity, low initial cost, long life, and minimum maintenance. The wound-rotor motor has for many years followed its own path, carving out an application niche of its own based on its unusual characteristics.**

WHEN A MAN has the job of selecting a motor for a given task, he has, essentially, four choices. If the machine to be driven must run at constant speed, his choice almost inevitably is a synchronous motor. This motor requires a source of direct current for excitation, suitable control, and is relatively expensive. At the other extreme, if a wide range of speed control is necessary, easily and efficiently, and if d-c power is available, some form of d-c motor is the probable choice. However, by far the majority of jobs in industry can be performed by the simple squirrel-cage induction motor. Its speed falls off only slightly with increasing loads. It has the great merit of being the simplest of all motors, requires the least control, and is lowest in cost. But its speed (on a constant-frequency, constant-voltage power supply) is dictated solely by the load; it is subject to no control.

There are, however, many applications for motors that do require operation over a limited range of different speeds. For these, particularly where direct current is not available, the wound-rotor induction motor is a good choice. Its control is fairly simple, and it has no commutator, with its attendant maintenance problem.

### Construction and Operating Characteristics

The speed at which an induction motor runs at a given load is determined by the electrical resistance in the rotor circuit. The greater the resistance the slower the motor runs; or, with resistance constant, increased load slows the speed. The two types of motors differ only in regard to this rotor resistance. In the squirrel-cage motor, it is fixed; in the wound-rotor motor, it is adjustable.

As its name implies, conductors in the squirrel-cage rotor consist of bars extending axially through each slot in the laminated core, the extensions of all bars beyond the rotor punchings being joined to rings at each end to form a complete permanently fixed rotor circuit. This rotor is shown in Fig. 1; typical speed-torque characteristics are shown in Fig. 2.

The conductors of a wound rotor are composed of coils placed in the rotor slots in the same manner as the stator winding. A typical wound rotor is shown in Fig. 3. The rotor coils are suitably interconnected and the leads brought out to collector rings that rotate with the shaft. Varying amounts of external resistance can then be inserted in the rotor circuit through brushes that ride on the collector rings.

The amount of rotor resistance in an induction motor is the factor that determines its general speed-torque characteristics. Hence any squirrel-cage induction motor, having fixed rotor resistance, is necessarily limited to a single set of speed-torque characteristics; thus its use is confined to applications for which the particular speed-torque characteristics are acceptable. However, this does not severely restrict the range of applications for squirrel-cage motors. Typical speed-torque characteristics for two popular types of squirrel-cage motors are shown in Fig. 2.

A wide range of speed-torque characteristics can be obtained from a single wound-rotor induction motor by varying the amount of external resistance in the rotor circuit. For example, the two families of curves shown in Figs. 4a and 4b are both attainable with the same motor, the difference resulting from the values of external secondary resistance embodied in the two controllers. The top curve in each family is for zero external secondary resistance (collector rings short circuited), the total resistance being that of the internal rotor winding. The remaining curves are with successively increasing amounts of external resistance in the rotor circuit, each increment being relatively larger in the case of Fig. 4b. Intermediate curves are available simply by inserting the suitable value of external secondary resistance.

Wound-rotor motors are customarily grouped in three categories, depending upon the application for which they are intended and the type of rotor-resistance controller used, although the distinction among the basic motor designs is

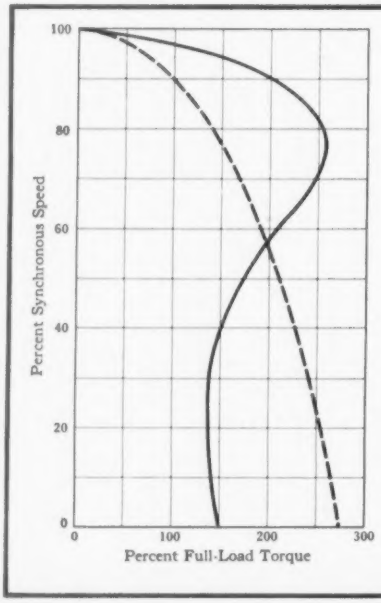



Fig. 2—Typical speed-torque curves for two popular types of squirrel-cage motors. Solid curve is a low-slip design; dotted curve a high-slip motor.

←

→

Fig. 4—Typical speed-torque characteristics of a wound-rotor motor with different controllers.

# Rotor Motor

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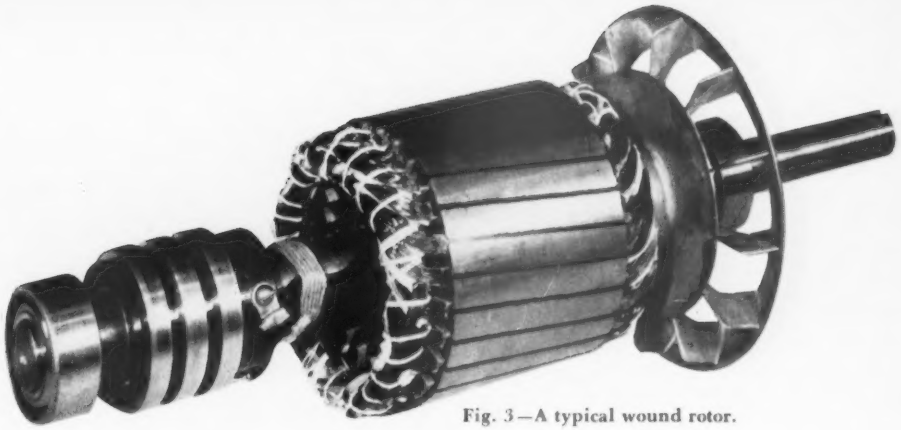


**Fig. 3—A typical wound rotor.**

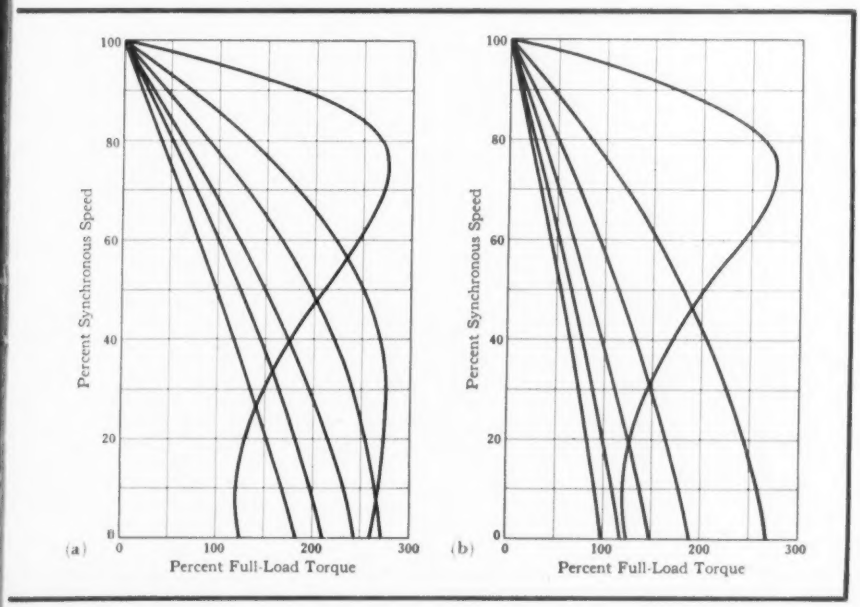
negligible. *General-purpose motors* are usually continuous rated and matched with secondary controller to provide characteristics per Fig. 4a. Operation below 50-percent speed is not recommended. *Crane and hoist motors* are intermittent rated and matched with secondary controller to provide characteristics per Fig. 4b. These may have slightly more breakdown torque than the general-purpose motor. *Special-purpose motors* are intended for applications of a special nature where the service and/or required controller is beyond the scope of the two standard categories.

An examination of Figs. 2 and 4 seems to indicate that, theoretically, a squirrel-cage motor could be designed to have a rotor resistance such that it could essentially duplicate any one of the speed-torque curves in Fig. 4. From a practical standpoint, however, this is not feasible. A duplication of any one of the speed-torque curves on Fig. 4a (or any other intermediate curve desired) could be accomplished with one squirrel-cage motor. In general this would be uneconomical and impractical from several points of view.

From a manufacturing standpoint it would necessitate an almost unlimited variety of rotor punchings, conductor sizes and materials, and end-ring sizes and materials to provide each required rotor resistance. This obviously would increase the cost and thus nullify one of the great merits of the squirrel-cage motor. The majority of applications for squirrel-cage motors can be adequately served by existing types.

Also, there is a limit to the resistance that can be built into a rotor "cage." Thus it is physically impossible to duplicate the lower speed-torque curves of Fig. 4 with a squirrel-cage induction motor.

There is another reason for not including all of the motor-secondary resistance within the rotor itself, even if it could be done practically. The rotor-circuit current through the resistance obviously creates heat. In a wound-rotor motor, by having some or most of this resistance external to the motor, the problem of heat dissipation is greatly simplified. Consider a typical case and consider that the rotor loss in an induction motor is proportional to the percent slip, which is the ratio of no-load speed minus full-load speed to the no-load speed. When the wound-rotor motor of Fig. 4 is operated with collector rings short circuited (i.e., maximum speed), the full-load slip is five percent. This five-percent rotor loss is all dissipated internally in the motor. With external resistance added to the rotor circuit such that the motor operates on, say, the lowest curve of Fig. 4a, the full-load slip is now 50 percent. However, of this large rotor loss, only the original five-percent loss is dissipated internally in the motor and contributes to motor heating; the remaining 45 percent is dissipated in the external resistors. Hence, for wound-rotor induction motors, regardless of how much the slip is increased by adding external resistance, the rotor loss dissipated internally is limited to the relatively small portion represented by the slip with the collector rings short circuited. With squirrel-cage motors, all rotor loss is dissipated in the motor itself. If it were operated at 50-percent slip, the resultant high rotor loss would limit the safe operating time to a brief interval.




Finally, any squirrel-cage motor, whatever its rotor resistance, has but one speed-torque curve, assuming operation at constant frequency, voltage, and stator circuit. Thus it does not offer the flexibility of operation on any one of several possible characteristic curves.

### Types of Application

With the foregoing short review of the wound-rotor motor's characteristics in mind,

its application capabilities can be more reasonably analyzed. Although there are numerous and varied applications for wound-rotor motors, the most common are those requiring speed variations. These can be subdivided into two classifications—variable-torque and constant-torque applications—which are quite readily defined.

**Variable- and Constant-Torque Applications**

A good example of a *variable-torque application* is a fan drive. The wound-rotor motor should be applied to fan drives in those cases where a varying volume of air is to be delivered. This is achieved by operating the motor at selected speeds between full speed and approximately 75-percent speed. However, where sufficiently accurate control of air delivery can be obtained by alternately operating the fan at one of two, three, or four definite speeds, a multispeed squirrel-cage motor should be used. This is accomplished by reconnecting the stator winding or by the use of different stator windings to give different numbers of poles. The potentialities of the multispeed squirrel-cage induction motor for fan drives or other variable-torque applications is shown in Fig. 5a. These curves show the speed-torque characteristics of various 60-cycle motors, each having a top speed of 1800 rpm (4 poles). Although the detailed curves would be somewhat different if based on a slower top speed, the trend would be similar. As the number of poles increase the maximum torque available drops off sharply. This is acceptable with fan drive, however, because the torque required to drive a fan decreases rapidly as fan speed is reduced.

Due to winding-space requirements (limiting the number of separate stator windings to two), only certain pole combinations are available in a given motor. Keeping these limitations of the squirrel-cage multispeed motor in mind, comparison of curves in Fig. 5a with those in Fig. 4a or Fig. 6 reveals that the available operating speeds for the multispeed squirrel-cage motor are in relatively large steps, whereas with the wound-rotor motor a series of closely spaced operating speeds is available, enabling closer control of air volume.

Of course, in many fan applications the amount of air to be moved is not particularly critical, for example, roof ventilators in a factory building. These applications are properly served by standard single-speed squirrel-cage motors, and adequate control of the air delivery is simply a matter of turning the motor off or on.

It is advisable to stress a limitation in the use of wound-rotor motors for applications involving speed reduction. Basically, the speed at which any induction motor runs depends somewhat upon the amount of load it is called upon to deliver. In Fig. 2 (solid curve), at 175-percent torque, the motor speed is approximately 93 percent of synchronous speed, while at 75-percent torque it is 98 percent. This is a relatively small change in speed for a considerable change in load, which is the reason the induction motor is thought of as an inherently constant-speed machine. However, whether the speed is 93 percent, 98 percent, or some other value is determined primarily by the load.

In the case of a wound-rotor unit having large external secondary resistance, this characteristic can lead to an operating speed quite different than intended. For example, consider the bottom curve on Fig. 4a, where the speed at 100-percent torque is 50 percent of synchronous speed. While this particular setting of external secondary resistance is commonly referred to as giving 50-percent speed reduction, obviously the speed is much greater than 50 percent if the load is decreased sufficiently. Thus, for very light loads, no appreciable speed reduction can be effected by adding external resistance in the secondary circuit.

To explain this point more fully, a specific example is illustrated in Fig. 6. The speed-torque curves of a 10-hp, 1150-rpm, wound-rotor motor with adjustable secondary resistance are plotted, together with the speed-torque curve of a typical fan. Since the torque requirements of the average fan vary as the cube of its speed, at slower speeds the required torque diminishes rapidly. For a given setting of external secondary resistance, the point of operation on the particular motor speed-torque curve will be where it is intersected by the fan speed-torque curve. At the secondary resistance setting that provides half speed (600 rpm), if normal full-load torque is required, the speed for this specific application is actually slightly more than 75-percent speed (900 rpm) because the torque demanded by the fan is much below that of full load. This condition must be taken into account when applying wound-rotor motors to fans and similar drives. Where a variable-torque application requires slow-speed operation, appreciably less than 75 percent of its high speed, a multispeed squirrel-cage motor should be used.

A good example of a variable-speed, *constant-torque application* is a conveyor that must be driven at different speeds, depending upon the desired rate of loading or unloading. The variable-speed characteristics of the wound-rotor motor are well suited to this application. However, the slowest operating speed of the motor should not be less than approximately half the synchronous (no-load) speed, for two reasons: first, although both rotor and stator losses of a wound-rotor motor at a given torque output are essentially the same at any reduced speed as they are at full speed, the lessened ventilation at the slower speeds causes overheating if such operation is prolonged; second, as Fig. 4b shows, the curve becomes so steep that a slight change in load produces a marked change in speed, with consequent danger of unstable operation.

Similar to the fan application, if the speed requirements of the conveyor can be satisfied by up to four definite speeds, then a multispeed squirrel-cage motor should be used. Typical

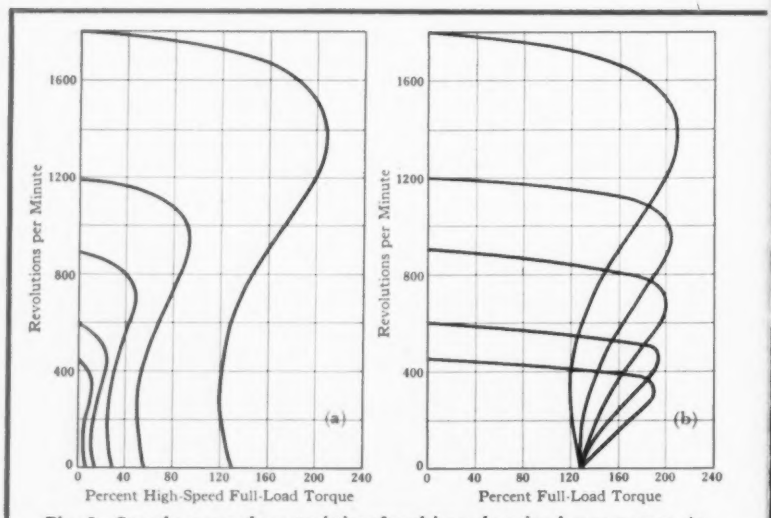



**Fig. 5—Speed-torque characteristics of multispeed squirrel-cage motors. At left, for variable-torque service; at right, for constant-torque service.**

speed-torque characteristics for constant-torque multispeed squirrel-cage motors are shown in Fig. 5b. Pole-combination limitations are identical to those of the variable-torque multispeed motor, as is the relative spacing of the available operating speeds as compared to the wound-rotor motor.

Another common application for wound-rotor motors is that requiring smooth acceleration combined with high torque. This application is exemplified by the large overhead crane. Both the hoisting and trolley movements are properly powered by wound-rotor motors, taking advantage of the low starting torque (see Fig. 4b) with maximum external rotor resistance; the external rotor resistance is then changed to successively lower amounts for increasing the speed and torque output of the motor, until the desired rate of hoisting or trolley motion is attained. Wound-rotor motors in hoist service are usually employed only in the larger cab-operated cranes that lift heavy loads, where a severe jolt at starting could be hazardous to personnel or equipment, and where a choice of hoisting speeds is desirable or necessary.

For smaller cranes operated from the floor and having only the hoisting movement powered, and where hoisting at only full speed is acceptable, high-slip squirrel-cage motors are almost universally used, since any jolting at start is of less consequence with the lighter loads. Also, the severity of the starting jolt can be minimized by "inching" the small motor, whereas this causes intolerable wear on large motors.

Inserting resistance in the primary circuit of a high-slip squirrel-cage motor produces a family of speed-torque curves as shown in Fig. 7. These speed-torque characteristics are reasonably equivalent to those of the wound-rotor motor of Fig. 4b. While it would provide the smooth acceleration required for larger cranes, the squirrel-cage motor would overheat if slow-speed operation were long continued.

For applications requiring a better controlled and smoother acceleration than afforded by the wound-rotor induction motor, a d-c motor is used, as in the passenger elevator.

**Special Applications**

For certain applications the characteristics of the wound-rotor induction motor make it the preferred drive. For example, take a cable-reeling machine. Cable is wound on a reel driven by a suitable constant-speed motor. Consequently the linear speed at which the cable moves increases as the reel fills up. The cable must be kept under slight tension as it is wound to prevent crossing or tangling on the reel. Further, while the amount of tension need not be perfectly constant, it should remain at a fairly uniform value to prevent too much stretch or too much slack. To accomplish this, the cable is controlled from an auxiliary drum connected to the shaft of a wound-rotor motor having very high external rotor resistance, such that its speed-torque characteristics are similar to, say, the lowest curve on Fig. 4b. The speed at which the wound-rotor motor runs depends on the linear speed of the cable, and even if this were to vary as much as two to one, the tension applied to the cable by the wound-rotor motor would be satisfactorily constant. Thus the steep slope of this speed-torque curve, which causes undesirable instability in some applications, becomes an asset.

In applications requiring development of torque at zero speed for any appreciable length of time, the wound-rotor motor can be used, although locked operation is not too desirable for any motor because of the large heat losses present under locked conditions. The wound-rotor motor is superior to the squirrel-cage for these applications for two reasons: first, the major portion of the rotor loss is dissipated in the external resistors without producing heat in the motor proper; second, extremely high rotor resistance gives minimum stator loss for a given locked torque.

Where capacity of the power supply is limited, the wound-rotor motor can be used for applications normally assigned to squirrel-cage motors, because it has the lowest starting current for a given starting torque of any induction motor.

Because their characteristics are somewhat similar, the choice between squirrel-cage and wound-rotor motors should be made carefully. Each has its own field.

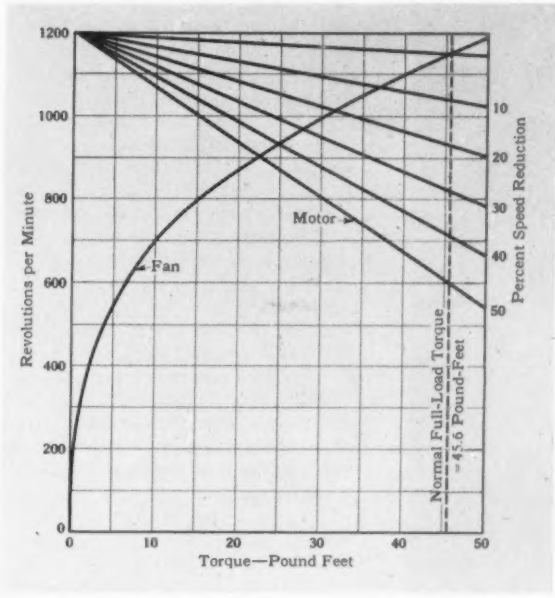



**Fig. 6—The speed-torque characteristics of a 10-hp, 1150-rpm wound-rotor motor having a 5-point secondary controller to give equal increments of speed reduction down to 50-percent speed at rated torque. The curve of a direct-connected fan load is also illustrated.**

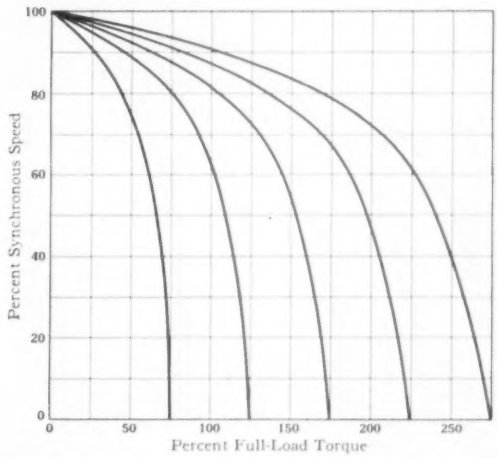



**Fig. 7—Speed-torque characteristics of a squirrel-cage motor with varying external resistance in the primary circuit.**

# *Personalities* in Engineering

In the fall of 1924, Edward Arnott, after six years of prep-school work at Ridley College, St. Catharines, Ontario, entered Princeton University in the School of Engineering. He had mechanical engineering in mind. An ambition no doubt inspired by his civil-engineer father, an Australian of Scotch descent, who had much to do with the construction of New York's Hudson and Manhattan tunnels. But Arnott was not destined to be a mechanical engineer. A few months after school opened, he happened one night to pick up a copy of Michael Pupin's *From Immigrant to Inventor*. "That remarkable book," Arnott says, "fired me with the desire to get closer to the fundamentals of things. Physics seemed to offer that opportunity."

By this chance event mechanical engineering undoubtedly lost a capable member, physics gained one. Quite likely the choice was fortunate, because physics has given Arnott the opportunity to exploit an unusually acute curiosity. This has applied to both his scientific and his personal life.

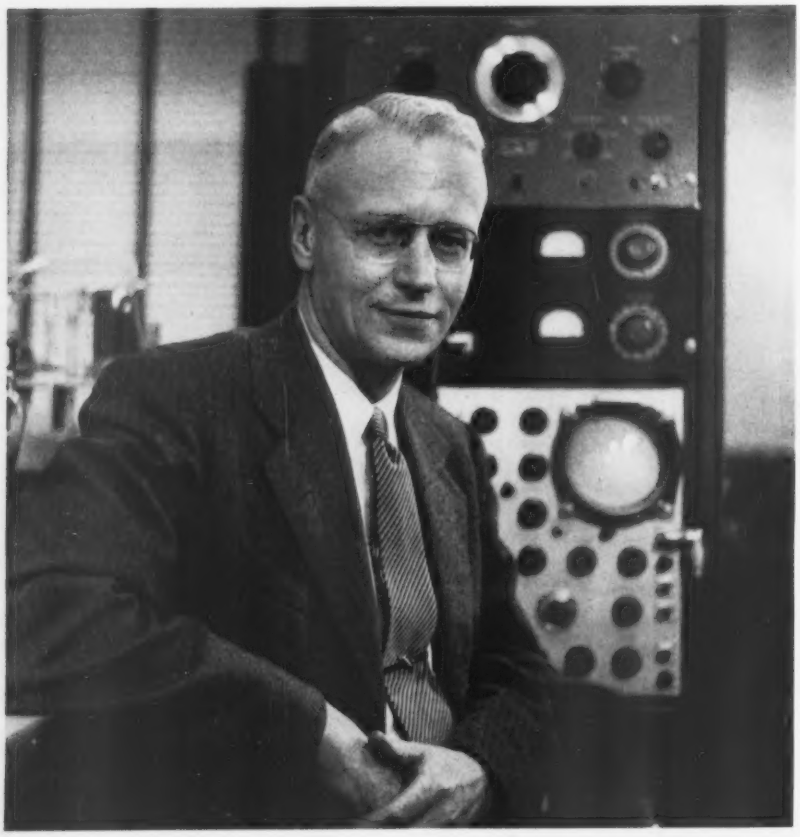
To Arnott the saw about old dogs and new tricks is baloney. Several years ago he was faced with the necessity for public speaking. A friend suggested he take vocal lessons to improve his microphone technique. Arnott found music to his liking. He applied himself with customary diligence, and is now an enthusiastic singer. He has been known, at the end of a serious scientific convention, to "bring down the house" with an impromptu song with Arnott lyrics.

Arnott started playing golf when 11 (there's that Scottish ancestry again!) and now has a very considerable reputation on the links. At least part of this reputation was created by his phenomenal feat of making a hole-in-one twice on the same 215-yard hole. He complains that, for lack of practice lately, he cannot consistently shoot par golf.

He has recently become interested in bowling, a sport in which he does not yet shine—somewhat to the satisfaction of those he consistently "takes" in golf. However, he has been seen on alleys some distance from his neighborhood, surreptitiously practicing with the tenpins. The result is inevitable.

This propensity to learn new things, to develop new skills is, of course, just what a scientist should have. When Arnott graduated from Princeton in 1928 with a B.S. in Physics, he stayed on to obtain a master's degree in same in 1929. He also completed much of the requirement for a doctor's degree, meanwhile acting as an instructor in physics. During this period he studied under Karl T. Compton on electrical discharges in gases, and worked with Harry Smyth (of Smyth Atomic Report fame) on molecular spectroscopy in nitrogen. However, illness, and the economy of the early 30's being what it was, made it impossible for Arnott to complete work on the doctorate.

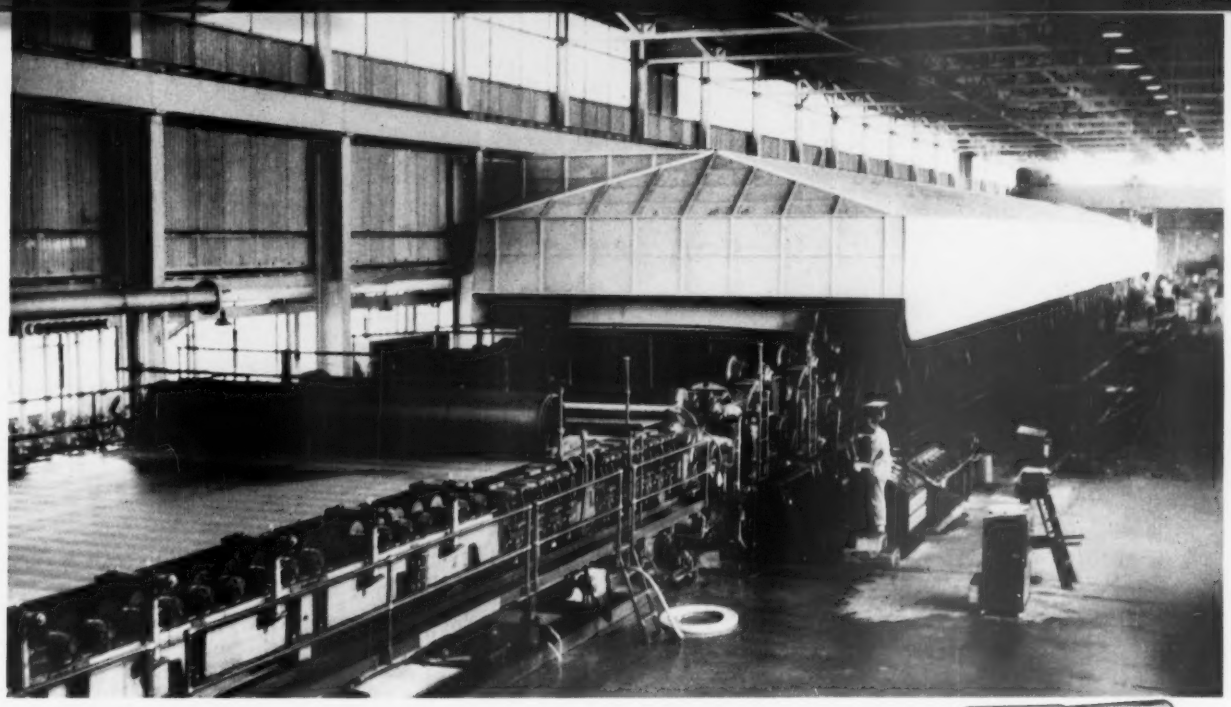
Then came a digression—fortunate, it has turned out—from science to engineering. In 1932 Arnott took a job with the Westinghouse Lamp Division at Bloomfield, New Jersey. The next 6½ years he spent in electronic-tube engineering, which experience has been a good leavening influence in his subsequent scientific career. About this time Westinghouse offered him a Lamme Scholarship, but circumstances, and a young family, forced him to decline. In this interval he worked on the earliest sealed ignitrons. This led to a transfer to research under Dr. Rentschler to look into the fundamental mechanism of ignitors and to develop coated-type ignitors. When this latter project was temporarily abandoned, Arnott was assigned to study the Sterilamp for bactericidal work, particularly in air-conditioning systems.



Came the war and Arnott was presented problems in connection with series spark gaps, high-pressure discharge tubes, and the then new methods for producing arcs and sparks. He was personally responsible for some of the enclosed-gap modulator tubes still used in radar circuits. In 1946 he was placed in charge of the group working on gas discharges. Two years later he was made assistant director of the Lamp Research Laboratories, under Dr. C. M. Slack; when Dr. Slack left to become technical director of the Westinghouse atomic-reactor division, Arnott took his place, the position he now holds.

Being a research director, Arnott can no longer probe personally into the unknown. He regrets this. However, he admits the position has its compensations. He can, in a general way, deal with a wider array of subjects, such as phosphors for television tubes, new light sources, and rare metals. One of his greatest satisfactions is learning how to plant new ideas for exploration with the members of his research staff.

Arnott's aggressiveness of spirit does not show in his manner. He is soft of voice, mild—almost reticent—in action. He has another characteristic that delights those who deal with him on matters of publicity—and no doubt many others: he has the facility of simple expression, the ability to present abstruse technical matters in easily understood form. He speaks never to impress, but to inform.




# *Paper-Mill Controls*—Fast, Precise, Dependable

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**The very fact that a paper machine can turn a water-thin mass of fibers into finished paper at speeds of several thousand feet per minute is sufficient testimonial to the devices that regulate the process. New regulators improve both the control and speed of this operation.**

In the paper industry, as in most continuous-process industries, speed is an economic necessity. But speed alone is not sufficient—it must be achieved at no sacrifice in quality. Thus the faster the process, the more accurate must be the regulators. The regulators most favored by industrial users to achieve these goals are of the magnetic type—rotating regulators and magnetic amplifiers. These regulators require less maintenance for long and dependable service.

The various phases of papermaking each have their own special conditions and requirements. New methods and systems now being applied to the most difficult control problems—the paper machine itself, its reel drive, the supercalenders, and winder drives—are outstanding examples of the precision and speed that can be obtained.

## The Paper Machine

The paper machine itself (Fig. 1) perhaps offers the most complex use of regulators. As paper mills grow larger and more complicated, the paper-machine sectional electric drive, i.e., one in which each section has its own drive motors, has increased advantages. The power that can be used to drive a section is unlimited; also the ease of control and flexibility is the same regardless of rating.

Increased speed and horsepower cause the regulator requirements for an electric sectional drive to become more exacting, since the machine friction load and inertia for different sections vary over a wide range. For example, in a modern high-speed drive, a couch section having almost a 100-percent friction load would have a 500-hp drive motor, while the dryer section with its tremendous connected inertia load would have a 150-hp drive motor.

Two methods have been used for regulating paper-machine sections—one based on the section's absolute speed and the other on its position relative to other sections. The absolute-speed method utilizes a tachometer to measure the speed of the section. The output voltage of the tachometer, which is proportional to speed, is compared to a master voltage refer-

**Fig. 1 (above)—The photograph shows a typical paper machine, consisting of a Fourdrinier (left), two press sections, four dryer sections, two calender sections, and a reel section. The schematic diagram is also of a Fourdrinier paper machine. Paper is formed on wire section at left, then pressed, dried, calendered, and wound.**

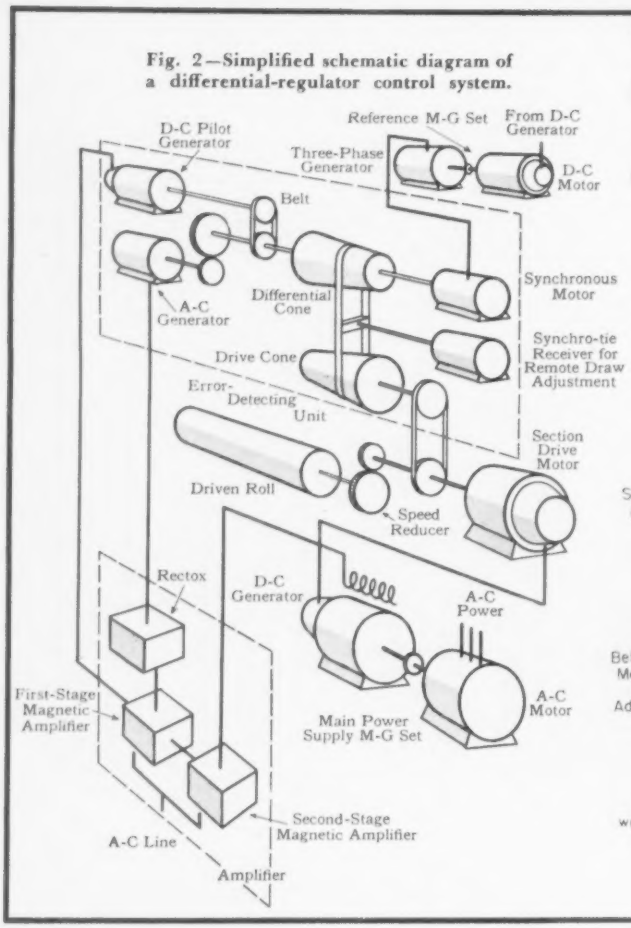



**Fig. 2—Simplified schematic diagram of a differential-regulator control system.**

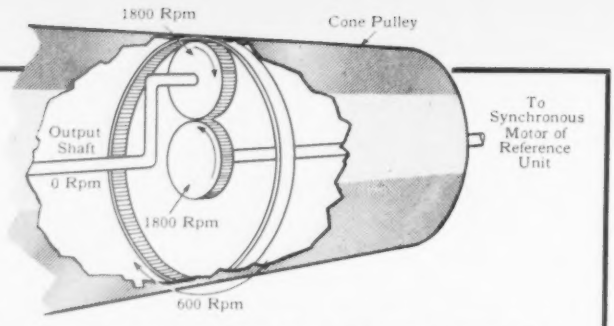
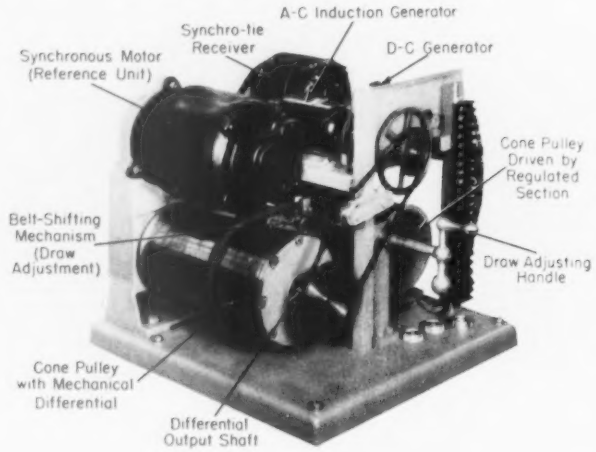



**Fig. 3—A cutaway sketch of the differential cone. The differential gear turns on its own shaft, but the output shaft itself turns only when a change in section speed is required.**

**The elements of the differential regulator.**




ence. The electronic paper-mill sectional regulator is an example of this absolute-speed type.

The most recent sectional regulator uses the position principle in combination with a quick-acting speed-responsive element and a magnetic amplifier (see Fig. 2). The main components of the regulator are: (1) an error-detecting unit, located adjacent to the regulated section motor, and (2) a magnetic amplifier and control unit that are part of the main d-c control panel for the drive. The error-detecting unit consists of a set of cone pulleys that are driven from the regulated section; a reference, which is a synchronous motor driven at a speed proportional to a master-set speed; a differential gear system for detecting any error between the cone-pulley speed and synchronous-motor speed; and output units that produce electrical signals proportional to the position of the differential output shaft and to its rate of change of position. The error-detecting unit also contains a Synchro-tie receiver to position the cone-pulley belt for remote draw adjustment.

The control unit contains two magnetic amplifiers, a first-stage unit for amplifying the electrical signals from the error-detecting unit, and a second-stage for furnishing controlled excitation to the shunt field of the regulated generator (or motor in the case of a single-generator drive). The control also includes damping and control transformers, Rectox rectifiers, and the necessary calibrating resistors.

In the error-detecting unit, a cone pulley is either chained or belted to the regulated section. This cone pulley drives a second cone pulley through a belt. Inside the second pulley is a planetary gearing system that constitutes a mechanical differential (see Fig. 3). One portion of this differential consists of a ring gear on the inner surface of the cone pulley. The other half of the differential is mounted on a shaft that extends inside the pulley. This shaft is driven by a small synchronous motor that receives power from a master frequency set; this set serves as a speed reference for the entire machine.

The output shaft of the differential is mechanically connected to a small a-c induction generator and a small d-c generator. The a-c generator is similar to an induction regulator in that it has a standstill output voltage that is determined by its rotor position. When the second cone pulley and the synchronous motor rotate so that both halves of the differential are at the same speed, the output shaft is at standstill; consequently, so are the small a-c and d-c generators. The standstill output of the a-c generator is rectified and fed into the magnetic amplifier and fixes the steady-state field excitation of the regulated generator. Normally, the output of the small d-c generator is also fed into the magnetic amplifier; however, its output voltage is zero at standstill.

Should an error develop in the speed relationship between the second cone pulley and the synchronous motor, the output shaft of the differential rotates. Thus the output voltage of the a-c induction generator changes in accordance with the change in its rotor position. The d-c generator now has an output voltage whose magnitude is determined by the speed at which the differential output shaft moves. This change in output of both the a-c induction generator and the d-c gener-

ator causes a corresponding change in the excitation of the regulated generator, thus bringing the motor speed back to its original value. Voltage amplification in the d-c generator circuit is relatively high as compared to that in the a-c generator circuit, assuring quick correction and restoration of speed to its original value.

A set of stops and a small slip clutch are mounted on the rotor shaft of the a-c induction generator to limit the rotor travel to about 55 electrical degrees for the regulating range. This makes the output of the a-c induction generator very nearly linear with position.

The a-c induction generator and the d-c generator are in motion only during the correction period. Under steady-state conditions, the only moving elements of the regulator are the cone pulleys and the synchronous motor.

Draw adjustment is accomplished by adjusting the position of the belt that connects the two cone pulleys. This belt can be positioned locally by means of an operating handle on the error-detecting unit, or remotely by means of a Synchro-tie system. Slack take-up is accomplished by means of a pushbutton-operated magnet coil that allows a momentary shift of the cone-pulley belt. This permits taking up slack between sections without disturbing the draw adjustment of the regulator.

#### Paper-Machine Core-Type Reel Drive

At the extreme dry end of the paper machine, the paper is wound on a reel. Certain machines use reels driven at the center or core, and such a reel requires a regulator to hold constant paper tension while the reel builds up from empty core diameter to full reel diameter (see Fig. 4). The reel motor receives its power from a generator whose output voltage is approximately proportional to the speed of the paper. The reel-motor shunt field is excited from two sources—the constant-potential exciter bus through a series resistor, which sets minimum motor field to prevent its loss, and a magnetic amplifier, which can strengthen, but not decrease, the field.

The magnetic-amplifier constant-tension regulator has four windings as follows: (1) an a-c winding that can be connected in the conventional doubler circuit; (2) a pattern-field winding, whose strength is adjustable over a range proportional to the desired tension range over which the reel must operate; (3) the current-measuring field winding, which measures the current in the reel-motor armature circuit; and (4) a positive-feedback winding, which allows increased amplification.

The function of the pattern and current-measuring fields is to hold reel-motor armature current constant as the reel diameter increases. Since the regulator works on the motor field, this is a constant-horsepower regulator.

A 164-inch-wide paper machine making saturating pulp (cellulose pulp used in making rayon) at a maximum speed of 300 feet per minute would require a 15-hp reel-drive motor to hold a maximum of six pounds-per-inch-of-width tension in a sheet of paper as it is wound on a reel with a 16-inch core diameter and a maximum build-up of 84 inches. The reel-drive motor would operate over a speed range of 380 to 2000 rpm through a 28-to-1 ratio speed reducer.

#### Supercalenders

After certain papers such as book, writing, and glassine leave the paper machine, they are taken to a supercalender to be given a hard surface. In the case of book paper, supercalendering improves the surface, allowing better definition of the printed character. The supercalender is not a continuous-process machine. Since it is idle for a minimum of 30 percent of the time for threading and splicing of sheets, the supercalender must be operated at the fastest permissible speed to make up for the time lost. As the speeds of paper machines increase, the speeds of the supercalenders tend to follow; for example, the maximum speed of supercalenders in 1930 was 1200 fpm; by 1940, the speed had increased to 1500 fpm; and today, 2000 fpm is becoming quite common. With all of this increase in operating speed, threading speed has remained at 50 fpm; the operator cannot conveniently handle more.

The rolls in the supercalender are made of steel and a soft material, such as paper or cotton. The hard and soft rolls are arranged alternately in the stack. A tremendous pressure—as high as 2000 pounds per inch of width—is applied to these rolls. Slippage of the rolls on the paper at the roll-contact points results in an ironing process. Application of pressure on the rolls causes the calender load to increase from about 10 percent to 100 percent of the rated value. Unless the pressure can be applied at the threading speed and the calender accelerated with pressure on, then the paper processed during each accelerating and decelerating period must be scrapped. On a 2000-fpm calender this means 350 feet of scrap paper.

The modern supercalender drive (Fig. 5) utilizes a Rototrol regulator to provide threading-speed regulation. This regulator allows the supercalender to be threaded at as low as one fortieth of the top operating speed, and 100-percent load can be applied at this low speed with no effect on paper speed.

The supercalendering process requires that the paper be unwound at the entry end and rewound at the delivery end using core-type reels. Electrically powered reels have proved the most satisfactory, and the most economical on a power-consumption basis. The reels are regulated by a combination of boosters and Rototrol regulators to provide constant tension in the sheet at threading speed, during acceleration and at any operating speed. The constant-tension reel regulators operate on the general principle previously explained for the center-wind reel at the dry end of the paper machine. Inertia compensation on the reel drive during acceleration and deceleration periods is relatively easy to accomplish by recalibration of the unwind and wind tensions during each rate-of-change period. Since the supercalender requires a relatively long period for acceleration (about 20 seconds), a motor-operated rheostat is used to achieve a constant rate of acceleration, and

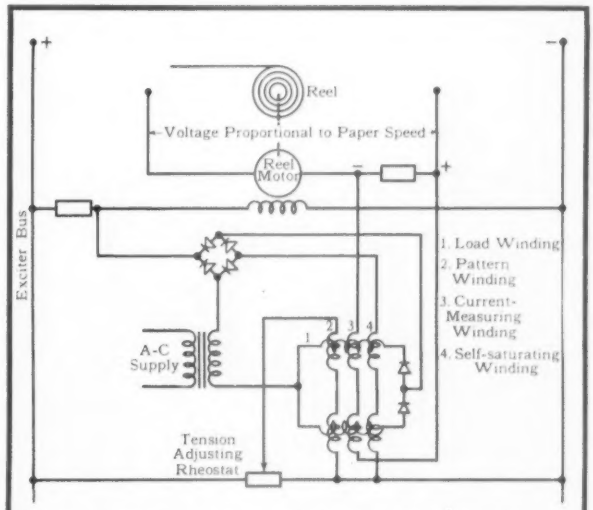
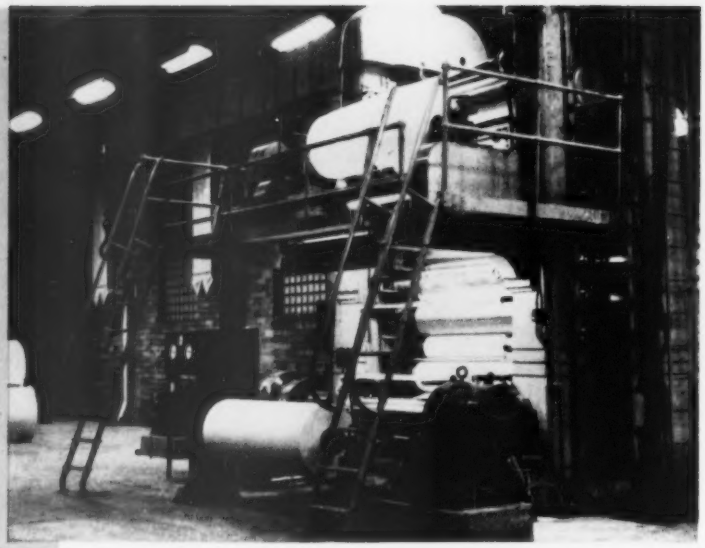



**Fig. 4—The magnetic-amplifier control for reel tension.**

**A 76-inch supercalender with adjustable-voltage d-c drive. Its operating speed is from 50 to 1800 rpm, with Rototrol regulator threading control.**



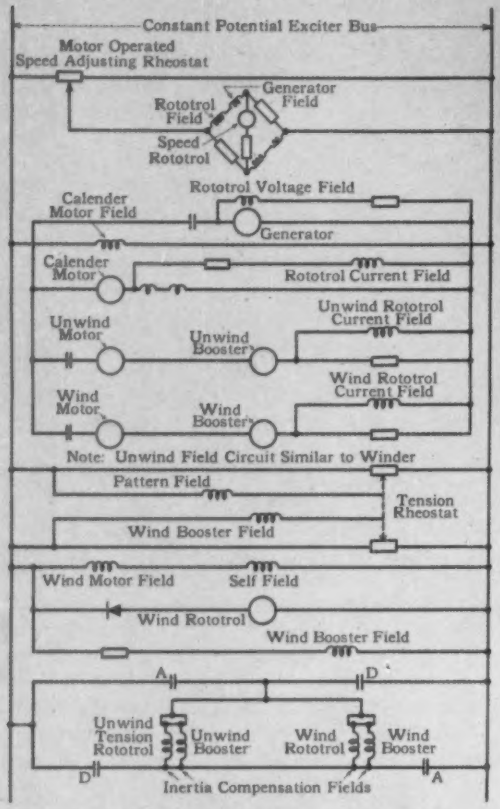



**Fig. 5—The principal circuits for a d-c adjustable-speed supercalender drive.**

inertia-compensation relays simply recalibrate the tension.

In addition to holding tension, the unwind reel is arranged to pay out paper while the supercalender is at standstill. The wind reel is arranged to operate at a peripheral speed slightly above the linear speed of the paper during the threading period. This allows the operator to get a tight initial wrap on the reel drum. Tension under stall condition is provided to allow splicing of the sheet to remove defective portions.

A 156-inch-wide supercalender finishing book paper at 2000 fpm might require a 400-hp main drive motor. To hold ten-

**The d-c control for a 238-inch-wide kraft paper winder. Magnetic-amplifier panels are at bottom. At left is the threading speed regulator with current-limit magnetic amplifiers for acceleration and deceleration. At right is the unwind tension regulator.**

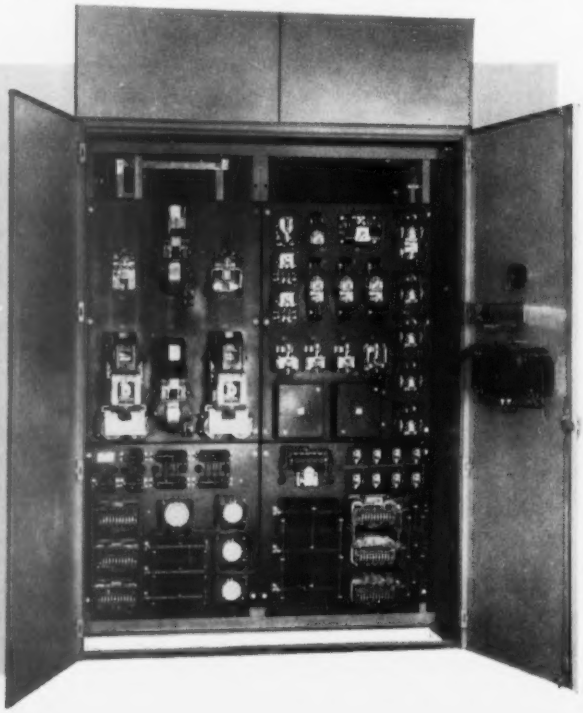
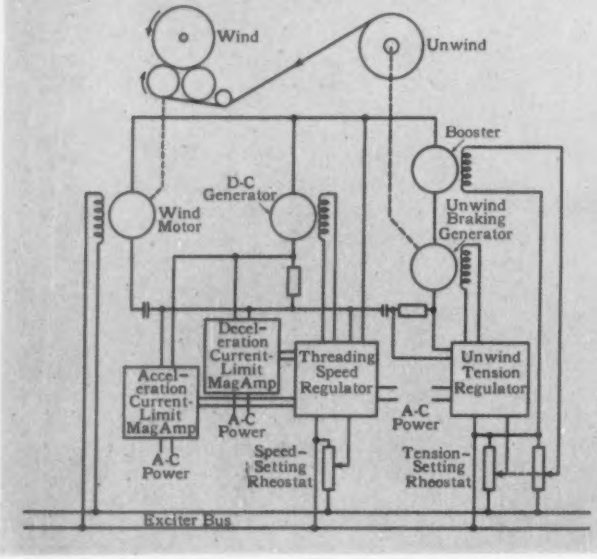


**Fig. 6—The main components for a d-c adjustable-voltage winder drive with electric braking.**



sions of four pounds per inch of width at the unwind reel and three pounds per inch of width at the wind reel, 40-hp reel motors would be required. Rototrol speed regulators on the supercalender stack and Rototrol tension regulators on the reels enable uniform, top-quality finishes at maximum rates.

**The Winder**

Following the papermaking machine or the supercalender, the paper is finally trimmed and wound into rolls of suitable size and weight for shipping. The winder is a start-stop process that must operate at a minimum speed of at least twice the maximum speed of the papermaking machine, since only one winder is usually provided for a given machine. A winder for kraft board may be operated at 5000 fpm. Huge 84-inch-diameter, 234-inch-wide rolls, weighing as much as 35 000 pounds, are rewound into shipping rolls 42 inches in diameter and 78 inches wide. A 400-hp winder-drive motor, a 187-kw unwind braking generator, and a 200-kw power-supply generator—all capable of handling 200-percent load during speed-change periods—are required to achieve reasonable production cycles.

The winder-drive motor is a constant-speed d-c motor that powers the surface wind drums; the unwind braking generator is an adjustable-speed d-c machine connected to a core-type unwind stand (see Fig. 6). After the drive is up to operating speed, the winder-drive motor runs at constant speed as the shipping roll builds up; the unwind braking generator, however, operates over a speed range depending on the change in diameter of the unwind roll. Tension in the paper is determined by the value of armature current in the braking generator. Speed of the paper is set by the speed of the winder motor, which in turn is related to the generator armature voltage. During the accelerating period, the tension in the paper depends not only on the armature current of the braking generator but also on the torque necessary to accelerate the unwind roll and braking generator. Thus, to maintain the desired tension, the armature current of the braking generator must be reduced during the accelerating period and increased during the decelerating period; this is called inertia compensation. When a motor-operated rheostat is used to accelerate and decelerate at a constant rate of change of speed, inertia compensation is relatively easy. On large winders where maximum performance of the winder is necessary, the maximum rate of change is limited only by the overload capacity of the electrical equipment. Thus, on large winders, current-limit magnetic amplifiers are used to set the rate of change of speed, and inertia compensation becomes more complicated. Typical winding cycles are shown in Fig. 7.

The stored energy in the unwind roll decreases drastically as the roll is paid out (see Fig. 8). The stored energy in the whole winder system including the unwind roll also changes, affecting the time required to accelerate and decelerate. The two changes in stored energy have a compensating effect, making a constant preadjusted amount of inertia compensation satisfactory. Relays that sense the change in speed indicated by movement of the speed-adjusting rheostat are used for initiating inertia compensation; and these relays remain actuated as long as the drive speed is being changed. Additional relays are used to recalibrate the value of current that the tension regulator holds during the accelerating and decelerating period, according to the unwind reel diameter.

The papermaking process is a continuous one, often operating seven days a week. Down time is expensive, so precision regulation, minimum maintenance, and service continuity are important. These systems help achieve optimum performance.

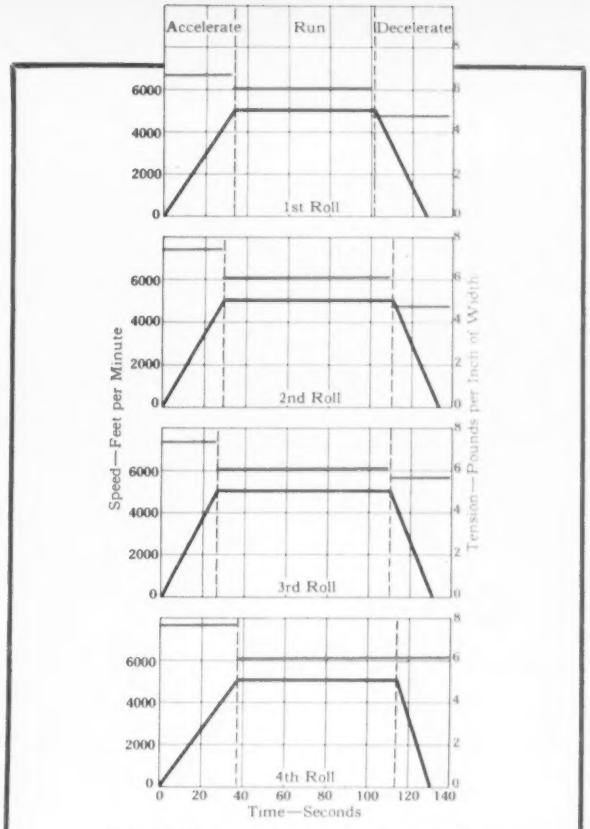



**Fig. 7—The cycles for winding four 9000-foot rolls of 0.0126-inch-thick paper, 42 inches in diameter, from one 84-inch roll.**

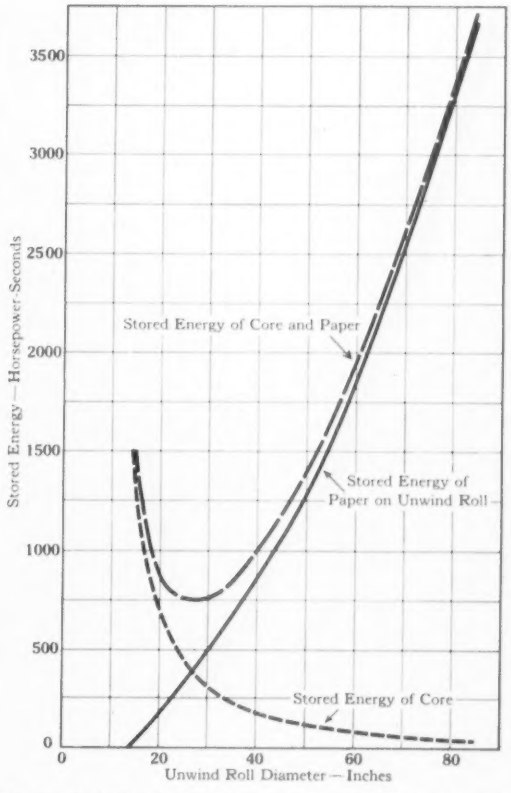

Stored Energy of Core and Paper
Stored Energy of Paper on Unwind Roll
Stored Energy of Core
Stored Energy—Horsepower-Seconds
Unwind Roll Diameter—Inches

**Fig. 8—Variation in stored energy as the roll is paid out.**

# *Pickling Lines for Steel*—A Start-Stop Proce

The economics of the steel industry and the high demand for its products combine to compel processes that are fast, thorough, and, where possible, continuous. Once the "batch" part of steelmaking is over, the steel thunders through a series of rolling mills and processing lines, each designed to perform some specific operation, and to do it with as little idle time as possible. One such process is *pickling*, whose principal purpose is to remove the scale left by the hot-rolling process.

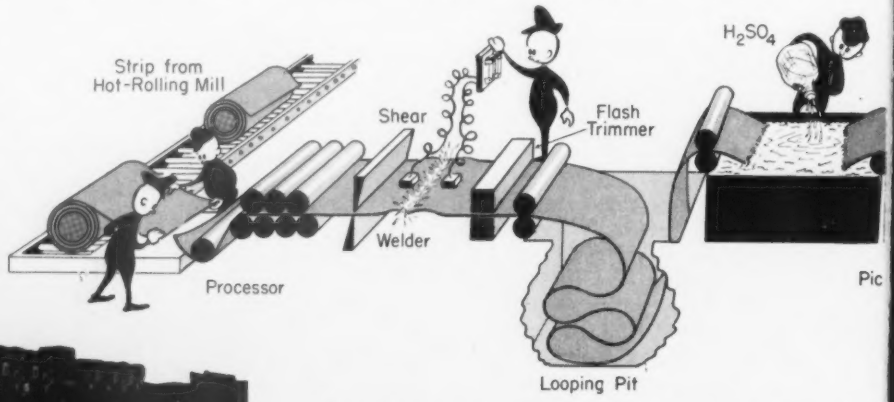
The surface of hot strip oxidizes very readily, and if this scale were not removed before the steel went to the cold-rolling mill, the resulting product might be pitted and discolored. This calls for a "bath" of hot sulphuric acid.

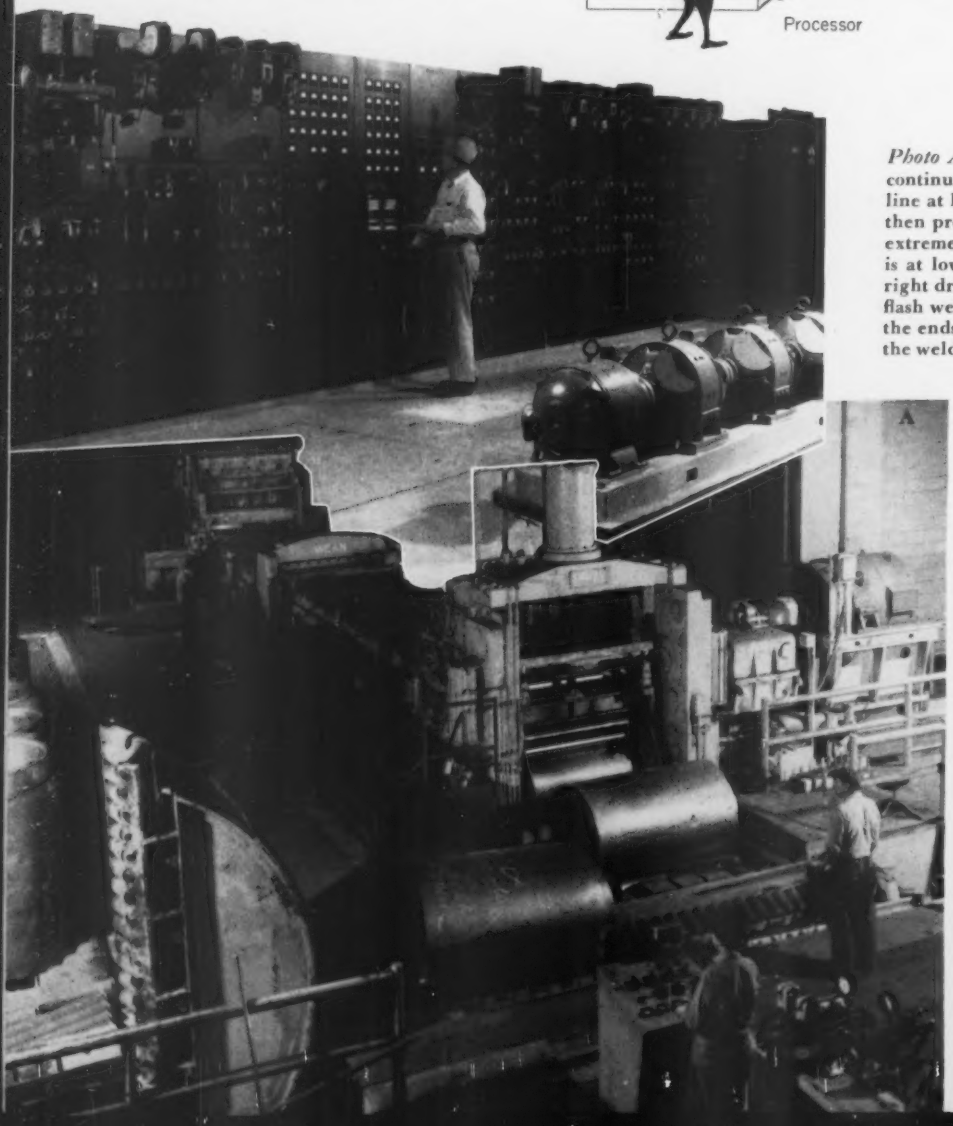
The word "continuous" as applied to a pickling line is a little misleading. The delivery end of the line is designed to be as continuous as possible, which in this case does not mean the entire line must be continuous. Consider the diagram below, and the accompanying pictures of a typical line—at the J & L Steel Corporation's Otis Works.

The short lengths (from 200 to 1000 feet) from the hot-strip mill are brought to the end of the pickling line by conveyor. The strip is first threaded through the *processor*, a group of motor-operated leveler rolls preceded by a breaker roll held down on the strip by air pressure. The strip makes a sharp turn around the breaker roll, thus cracking the scale, and then is straightened by the leveler rolls. As it is further threaded through the line, the leading end of the strip is squared off by the *shear*. Then it proceeds to the *welder*, where, amid a shower of sparks, it is flash welded to the end of the preceding strip. The small build-up of material left by the welding is then sliced off by the *flash trimmer*, the next step on the line.

Obviously, the entry end of the pickling line, i.e., the part thus far described, is not continuous. It must be stopped intermittently for trimming and welding operations. Thus for the delivery end to be continuous some sort of "storage" for strip must be available in the line itself. This is done with a *looping pit* located just ahead of the pickling tanks. The strip is

**Below is the motor control for the pickling line. Metering for the entire board, and rheostats for tuning and adjusting the drives are grouped in the center for the electricians' convenience. The Rototrol regulators in the foreground regulate the line generators and make possible very fast acceleration and deceleration while keeping motor currents within safe limits.**



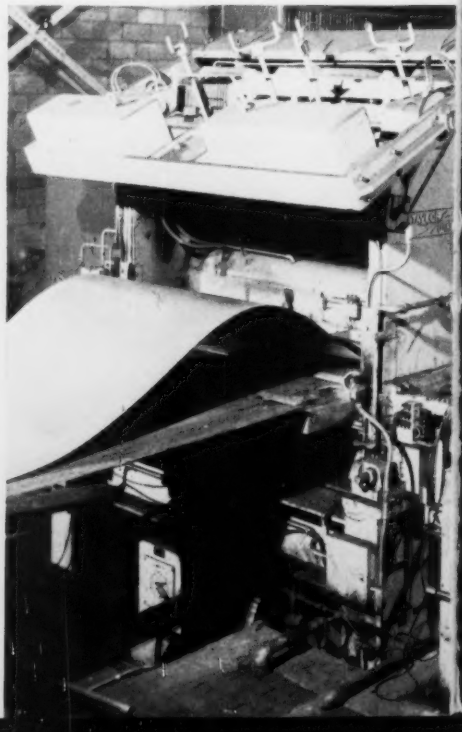


***Photo A*** **(below left)—This is the front end of the 80-inch continuous pickling line. Hot-rolled coils of strip enter the line at left. Strip is threaded through the processor (center), then proceeds to the shear (upper left). The welder is at the extreme upper left. One of the 13 control desks for the line is at lower right; the 400-hp drive motor visible at upper right drives the processor.** ***Photo B*** **(center)—A close-up of the flash welder. When this portion of the line is stopped to weld the ends of the two strips, a small loop is left on either side of the welder, as shown, to make certain the two ends are forced**

# ss Made Continuous

simply allowed to run into the pit, where it winds back and forth on itself much like a piece of Christmas candy.

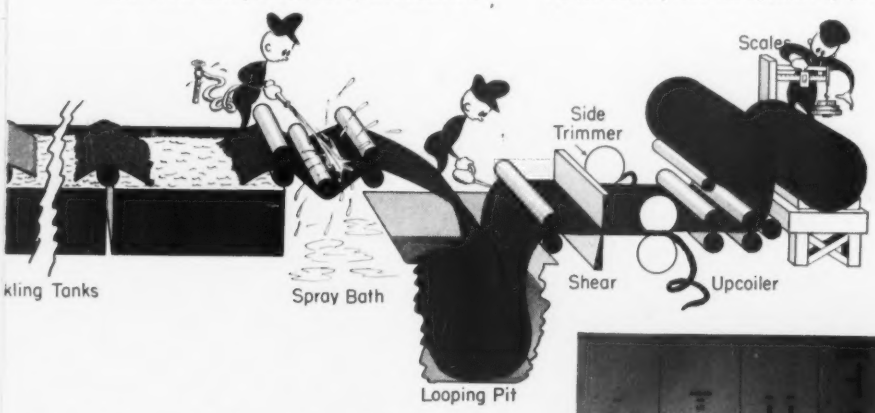
From the entry-end looping pit the strip passes through a series of *pickling tanks*. The acid in these tanks, in effect "etches" the metal; by proper control of time in the tank, the acid is allowed to remove only the oxide, leaving the base metal clean. The tanks themselves are made of steel, coated with rubber on the inside with a further protective layer of acid-proof brickwork as protection against the sulphuric acid. The acid content is initially from 10 to 26 percent by volume, decreases through use gradually, and is dumped when it reaches less than about three percent. For faster action it is heated to 190–210 degrees F by injecting steam into the tanks. A water spray bath rinses off the acid after the pickling is completed. A magnetic *loop regulator* detects and controls the loop's position within the tanks.

Once out of the pickling tanks, the clean strip passes through a set of pinch rolls, thence into another looping pit. This pit can be filled with oil to coat the strip as protection against oxidation. The strip then proceeds through another set of pinch rolls to the *delivery-end shear*, which cuts the strip after the desired length has passed. It then passes through the *side trimmer*, whose knives trim the strip to the desired width.

At the delivery end the *upcoiler*, by proper arrangement of a set of several rolls, imparts a curve into the strip so that it automatically coils itself. This eliminates the need for a reel. Finished coils are weighed and moved off the line by crane, ready for the next step in the process, usually a cold-rolling mill.

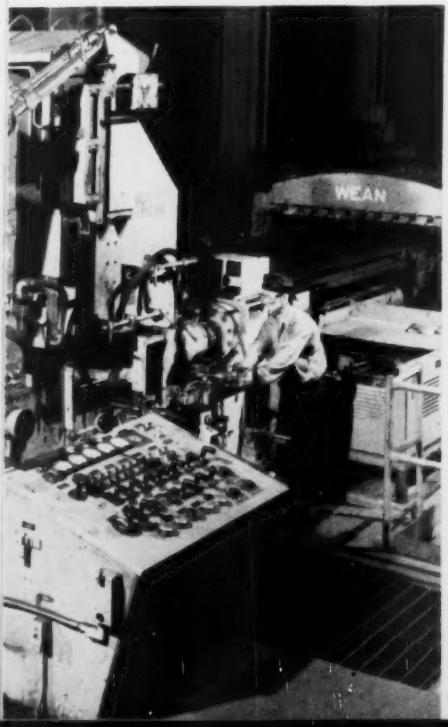
Close control of individual steps, as well as overall control of the line, is an obvious necessity. One reason for this is the difference in operating speed between the two ends of the mill—the entry end operates at two to three times the speed through the pickling tanks. Another is the precision needed for each individual operation of the line.

A total of 13 operators' stations is used to control the pickling line shown on these pages.




**Below, the "brains" for the welder and the "brawn" for the drive motors. In the background is the welding control, which maintains welding current at precise values. To the right of this control is part of the five-unit m-g set that supplies power to the line's drive motors; it contains one 1500-hp driving motor, and one 500-kw, two 200-kw, and one 50-kw generators.**

**against the gauge that sets their separation at the start of the welding cycle. At the control desk the operator can adjust welding time and current for the strip being processed, as well as the strip speed. The entire welding process takes between 5 and 20 seconds, depending upon the grade of steel, its width and gauge.** ***Photo C*** **(below right)—The delivery end of the line. At upper right are the pickling tanks. A finished coil from the upcoiler (at left) is 18 to 72 inches in width and weighs up to 30 tons. The upcoiler is driven by a 75-hp motor.**

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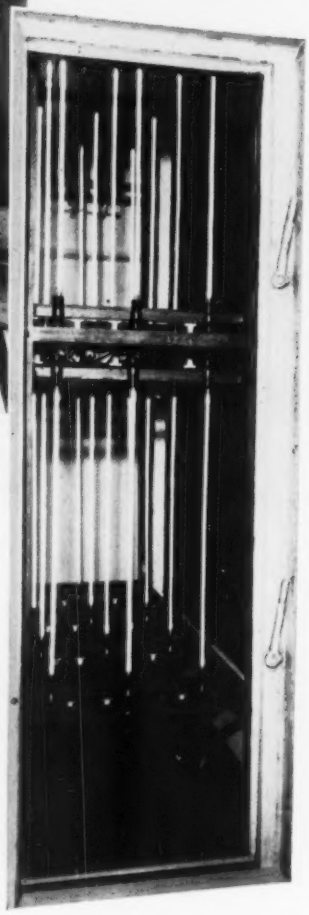


**Left, a Sterilamp installation in the air-conditioning system of a pharmaceutical laboratory. Below, an installation in which limited duct length was compensated for by using two banks of lamps.**

# Sanitization of Air by *Ultraviolet Radiations*

R. Nagy and G. Mouromtseff — *Lamp Research Laboratories*
F. H. Rixton — *Lamp Engineering Dept.*
*Westinghouse Electric Corporation*
*Bloomfield, New Jersey*

**The word lamp usually conjures some picture of a light-giving device. In recent years, however, some spectacular advances have been made by "lamps" in which visible light is but an unused by-product. Such a device is the Sterilamp, whose primary purpose is to sanitize, i.e., kill the bacteria, in air. Proper application of these ultraviolet-emitting lamps produces remarkably high-percentage kills of bacteria.**

Sterilization of air in air-conditioning systems can play a major role in preventing the spread of air-borne infection wherever people congregate. Disinfected air from such ducts can have a bacteria count lower than that of outside air, despite the fact that the indoor air is recirculated many times. Air sterilization is a necessity in such fields as food, drug, and pharmaceutical production. For processing of products from penicillin to pork, from bandages to beef, modern sterilization methods can be applied easily and profitably to air-conditioning installations.

A most effective and simple method of reducing bacteria and virus content of air is by ultraviolet radiations in air-conditioning ducts. To the five important functions already performed by air conditioning—control of air temperature, humidity, circulation, ventilation, and cleanliness—is added a sixth, air sanitization.

Filters are an effective means of removing dust, pollen, and other large air-borne particles, but against bacteria and virus microorganisms even the most efficient filter is only partially effective. Bacteria removal is a job best accomplished by the germ-killing rays of ultraviolet lamps. Laboratory tests have led to the development of an efficient, high-intensity, ultraviolet source, the Slimline Sterilamp. Large volumes of air can be disinfected by a small number of these lamps requiring only simple installation.

### Initial Research Was Inconclusive

Much of the early research into the effects of ultraviolet on microorganisms was confusing, and some was contradictory. The pioneer work was done by two Harvard University scientists in the early 1930's. Their results indicated that ultraviolet radiation was more effective at higher velocities of air flow; but they concluded that variation in humidity was the cause, and that ultraviolet sources were ten times as efficient at low humidities than at high humidities. Other research seemed to confirm this theory. However, in none of these tests was the output of the source measured at different velocities, nor was the amount of energy necessary to destroy a bacterium determined.

A short time later, two Westinghouse scientists—Rentschler and Nagy—demonstrated that organisms definitely were more readily destroyed at high air velocities. But at the same time

they found no effect of humidity on the rate of bacteria killing. They did learn, however, that the arrangement of lamps with respect to air flow was extremely important if full use was to be made of the available ultraviolet energy. And while other scientists were getting results that indicated that bacteria were extremely hard to kill at high humidity, the data obtained by Rentschler and Nagy showed that even the most resistant organism can be readily destroyed at high humidity. Plainly, much more information was needed, so an intensive study was undertaken in 1941.

**Recent Results Clarify the Situation**

Since 1941, considerable data has been collected in the Westinghouse Lamp Research Laboratories during studies on the bactericidal efficiency of ultraviolet lamps in air-conditioning ducts. The effects of different duct sizes, lamp types, wattage, and arrangements, variable humidity, air speed, different kinds of bacteria, and various methods of collecting bacteria samples were studied. Parallel to the bacteriological work, considerable experimentation was done on the development of an efficient ultraviolet source especially for air ducts.

Bacteriological tests to determine the effectiveness of ultraviolet lamps in ducts were made in an air-conditioning system supplying 5800 cubic feet per minute of air to an auditorium. Sterilamps were placed across the center of an enlarged portion of the air duct with their axes perpendicular to the air flow. The lamps were evenly spaced, the wiring was arranged so that various groupings of lamps could be operated to change the intensity in the chamber; the air source was adjustable to produce several air velocities.

The different methods of bacteriological sampling used gave comparable results. These were performed over a period of many months with humidities ranging from 24 to 60 percent. Tests were performed using two ultraviolet sources: the standard Sterilamp (type 782) operated at 0.050 milliampere and the newly developed Slimline Sterilamp (type G36T6) operated at 420 ma. The percent survival of the two lamps is shown in Fig. 1. A comparison of these curves shows that the newer lamp is much more effective in killing organisms than the earlier version. Examination of Fig. 1 also shows that less energy is necessary to destroy the organisms at higher air velocities than at lower velocities. Results further showed that, at a high percent kill, humidity does not affect the vulnerability of the air-borne organisms to ultraviolet radiations. The apparent greater efficiency of killing bacteria by the ultraviolet radiations at high-survival values must be associated with some other factor than humidity. The greater bactericidal efficiency at higher velocities would indicate that air turbulence may be this factor.

Increasing the velocity of air in any duct increases turbulence. Present results show that as turbulence is increased in this manner the organisms are more easily destroyed by the ultraviolet radiations. Some of the organisms in the turbulent flow apparently receive more radiation than would be expected from the average calculated intensity and time. The fact that the amount of radiation needed for a given kill decreases as air velocity increases is shown in Fig. 2.

**Operation of the Sterilamp**

Most ultraviolet sources operate at highest efficiency under approximately room-temperature conditions. The output of

TABLE I—CHARACTERISTICS OF THE SLIMLINE STERILAMP*

| | | | | |
|---|---|---|---|---|
| Operating current, amperes | 0.120 | 0.200 | 0.300 | 0.420 |
| Open circuit voltage | 600 | 600 | 600 | 450 |
| Operating voltage | 180 | 150 | 130 | 115 |
| Watts | 17 | 25 | 32 | 39 |
| Ultraviolet intensity (microwatts per square centimeter at one meter) | 70 | 100 | 115 | 120 |
| Ultraviolet output at 2537 A, watts | 8 | 11.4 | 13.1 | 13.8 |
| Rated life at 12 hours per start, hours | 6000 | 6000 | 6000 | 6000 |

*Values given are for operation at 80 degrees F in still air.

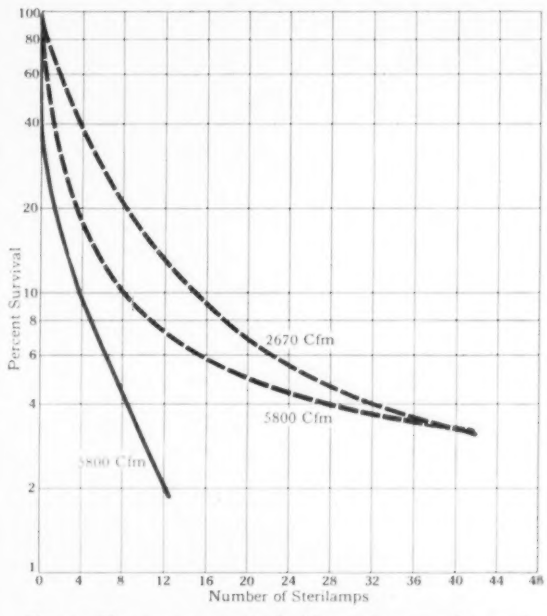



**Fig. 1—The percent survival of bacteria exposed to various numbers of Sterilamps. The two dotted-line curves are for type 782 lamps in an irradiation chamber of an air circulating system. The lower curve is for the newer type G36T6 Sterilamp in an air duct. The effect of different rates of air flow can also be seen in the upper two curves.**

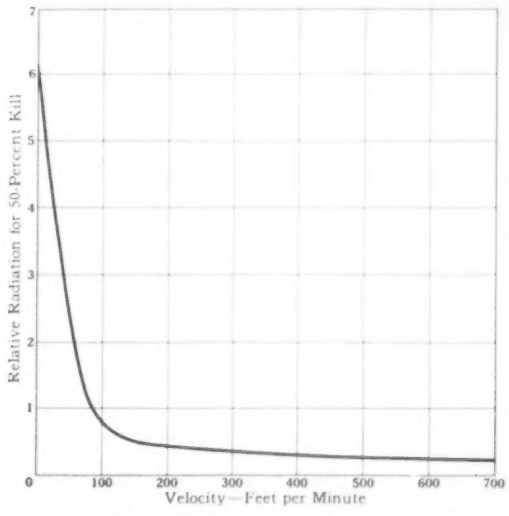



**Fig. 2—The relation between the amount of ultraviolet radiation required for a 50-percent bacteria kill and the velocity of the air in the duct.**

such a lamp, for example, the standard Sterilamp (type 782), diminishes as the temperature increases or decreases from this optimum region; the output at 40 degrees F, for example, being roughly two thirds of the output at 80 degrees F. Air drafts passing over the lamp cause a similar decrease in output by cooling the lamp to a temperature somewhat below its normal operating temperature. An attempt to provide a lamp that gives optimum output under operating conditions prevalent in air-conditioning applications led to the development of an inexpensive, high-intensity ultraviolet source. This lamp is known as the G36T6 in the nomenclature of the industry, but the Westinghouse design is actually made with the smaller T5 envelope, because this makes possible higher intensity under all air-duct conditions than with the T6.

The new Sterilamp operates on readily available fluorescent lamp ballasts and has the advantage of being heavily loaded, thus retaining high output under low temperature or severe draft conditions. It can be operated at 120, 200, 300, and 420 ma, depending upon the transformer selected. Approximately 95 percent of the lamp's radiations are at 2537 Angstroms wavelength, which is in the region of the spectrum that has the greatest germicidal effectiveness. The characteristics of the new Sterilamp are shown in Table I.

The ability to operate the lamp at high current results in greater ultraviolet output, which reduces the number of lamps required to produce a given ultraviolet concentration. The effect of operating current on the ultraviolet output of the new Slimline Sterilamp at ambient temperatures from 30 to 110 degrees F, under still air conditions, is shown in Fig. 3. High lamp loading (watts per unit area of bulb surface) causes greater outputs to occur at lower ambient temperatures as the lamp current is increased; optimum output is at 95 degrees F for 100-ma operation, 75 degrees F for 200 ma, 60 degrees F for 300 ma, and 40 degrees F for 420 ma. Air movement displaces these optimum points. Readings for Fig. 3 were taken at 100 instead of 120 ma for convenience.

When a Sterilamp is subjected to draft, the movement of air cools the bulb, causing the lamp output to change. The ultraviolet outputs resulting from operating the Slimline Sterilamp at ambient temperatures of from 30 to 110 degrees F and subjected to draft velocities of 100, 450, and 950 feet per minute, are shown in Fig. 3. A comparison of these curves shows that the optimum output conditions change as the air velocity and ambient temperature vary. Lamps designed to operate in still air decrease in output as draft velocities are increased. The Slimline Sterilamp, designed for operation in air ducts, produces a comparatively uniform output regardless of air velocity at ambient temperatures between 60 and 90 degrees F; and at ambient temperatures above 90 degrees F, lamp output actually increases with draft velocity. The effect of air velocity on lamp output at 80 degrees F ambient is shown in Fig. 4.

Arrangements of lamps have been studied so as to utilize the ultraviolet radiations to the fullest extent. Drafts parallel to the lamp axis allow slightly greater output under most conditions. When lamps are placed parallel to the air flow, bacteria traveling through the duct are irradiated only while they move opposite the lamp. Radiations emitted from the lamp travel only a short distance before being absorbed by the duct walls. This is especially true if the lamps are mounted on the walls. The same lamps placed perpendicular to the air flow are much more effective because of a greater "ray length," i.e., the ultraviolet radiations are not absorbed by the duct walls. However, if the ultraviolet lamp has not been designed for operation in moving air, the output is unsatisfactory. The output of Slimline Sterilamps operated at different current ratings varies only slightly in effectiveness with the temperature and the air velocity, whereas those lamps designed to operate in still air show a much greater variation in output. The most effective arrangement of Sterilamps operated at 420 ma in air ducts is with lamps perpendicular to the air flow and equally spaced about the center of the duct. In this position the greatest "ray length" with minimum shadow effect (ultraviolet absorption by other lamps) is obtained.

#### Practical Applications

Through exhaustive laboratory tests Sterilamp ultraviolet applications have been carried well beyond the realm of theory. Using the information obtained, the amount of energy needed to eliminate 90 percent or more of the organisms in the air was determined. The efficiency of the installation at air velocities common to air ducts increases with the size of the exposure chamber, as would be expected from the increase in ray length (see Fig. 5). These curves are helpful in calculating the amount of ultraviolet energy necessary for most ducts. However, in certain large irradiation chambers the length may be as short as two feet while the width and height may be much greater. In such instances, the chamber can be divided into two or more sections to simplify calculations. The ray length increases with the size of the exposure chamber and,

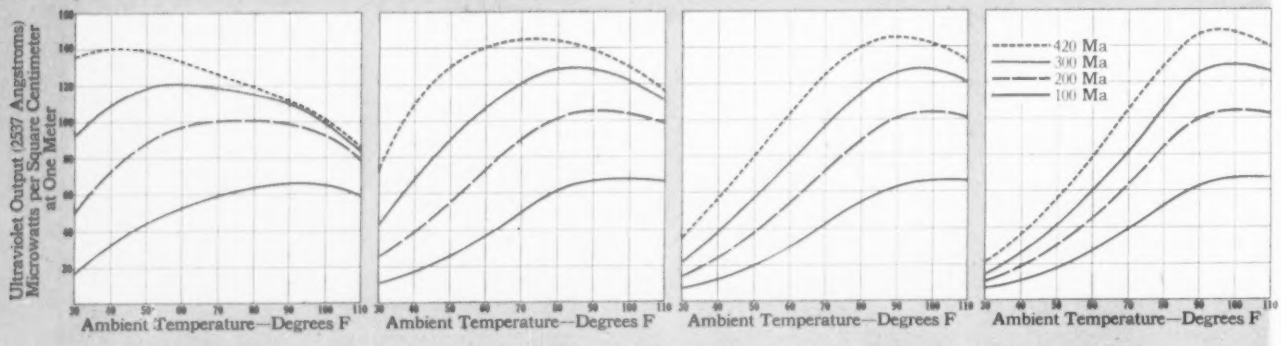



**Fig. 3—These curves show the effect of different draft velocities on the ultraviolet output of the type G36T6 Sterilamp over the same range of ambient temperatures. Curves at left are for still air; successively, from left to right, the other curves are for drafts of 100, 450, and 950 feet per minute perpendicular to the lamp.**

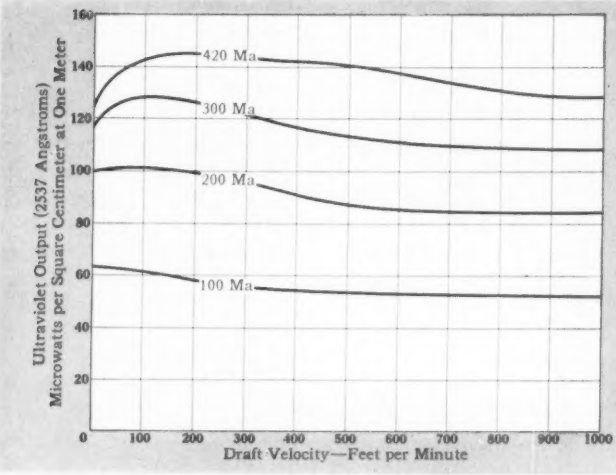



**Fig. 4—This group of curves shows the effect of draft velocity on the output of a type G36T6 Slimline Sterilamp, for several values of lamp current.**

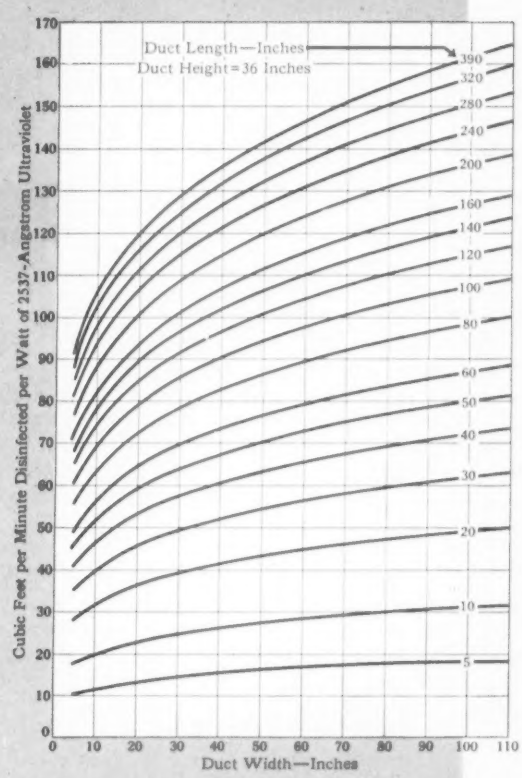

Duct Length—Inches
Duct Height = 36 Inches
Cubic Feet per Minute Disinfected per Watt of 2537-Angstrom Ultraviolet
Duct Width—Inches

**Fig. 5—The computed number of cubic feet of air that can be disinfected to a ten-percent survival value by a watt of 2537-Angstrom radiation from a G36T6 lamp, in various sizes of ducts.**

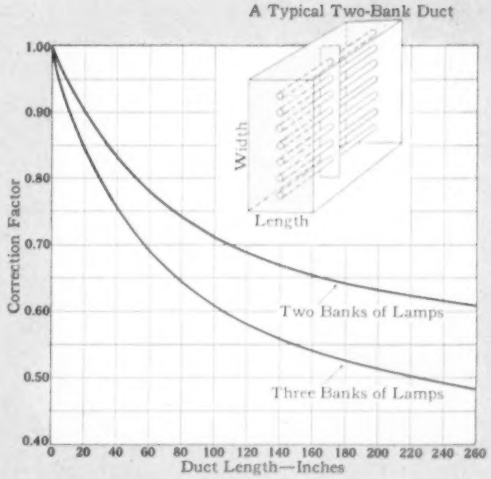



**Fig. 6—The correction factor used with Fig. 5 for calculation of air ducts having two or three banks of lamps.**

therefore, less ultraviolet energy is necessary. A correction factor for the increased ray length for various large irradiation chambers is shown in Fig. 6. All calculations of the energy required for various duct sizes were based on actual energy measurements in a nonreflecting duct. Some increased output is obtained by increasing the reflectivity of the walls.

To determine the amount of energy necessary for other than a 90-percent survival ratio, the experimental curve in Fig. 1 should be used. For example, to obtain a smaller survival value the ultraviolet wattage obtained for 90-percent disinfection should be multiplied by a correction factor; for 95-percent kill, this is 1.8; for 98-percent kill, 3.0; and for 99-percent kill, 3.5.

In the average installation, a 90-percent kill is recommended. This is usually equivalent to outside fresh air. Such a rate of air sanitization is used in most installations to protect personnel from cross-infection. In some, however, such as hospitals and pharmaceutical laboratories where absolute sterility is often necessary, the highest degree of bactericidal reduction possible is most desirable—at least 98 percent. In these installations the number of lamps in the air-conditioning system is simply increased, using the aforementioned curves (Fig. 1) as a guide.

One method of controlling odors emanating from air-conditioning systems, from the products in the room or from the personnel themselves, is by ventilation. That is, about ten-percent outside air is mixed with the recirculated air to impart some "freshness" to the indoor atmosphere. Ozone can oxidize many odors. This form of oxygen ($O_3$) is found in outside air at an average concentration of approximately 0.025 parts per million by weight. Ozone greatly contributes to the "freshness" of clean outside air. However, ozone is a very unstable molecule, reverting to oxygen ($O_2$) on making contact with organic matter or surfaces, so that little, if any, ozone is ever found indoors. It is possible now to make Sterilamps that produce controlled amounts of pure ozone. These lamps can be combined with non-ozone types in air-conditioning systems to supply ozone concentrations comparable to those found in outdoor atmosphere and thus destroy odors in addition to sterilizing the air.

Thus, using the ultraviolet radiations, indoor air can be sanitized and deodorized merely by installing Sterilamps in air-conditioning systems. The proper design of the duct installation is relatively simple and results are highly efficient in removing bacteria from the air.

# The *Electronic* Fluoroscope

**The x-ray tube was the first electronic device of widespread practical importance. Yet, curiously, conventional x-ray equipment shunned electronic devices for control, timing, and detection. This has been corrected in the last decade. Now a new device—the electronic fluoroscope—gives electronics a new and critical role, that of improving the image from which physicians make x-ray diagnosis. The resulting fluoroscope image is brighter by a factor of at least 200 times.**

FITZ-HUGH MARSHALL, *Research Laboratories, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

X-RAY fluoroscopes are notable for two very different features. On the credit side, they offer the physician the invaluable opportunity to observe the internal workings of the human body as they occur; but on the debit side is the fact that the images on the fluoroscopic screen are extremely low in brightness and difficult to see, necessitating several minutes, at least, of dark adaptation for the doctor. And even at that, much detail is not visible. A new device—the electron fluoroscope—improves the image brightness by a factor of some 200 times, adding materially to the information readable from the fluoroscope, as well as eliminating the necessity for dark adaptation.

The electronic fluoroscope replaces the conventional fluoroscopic screen on which the physician sees the living x-ray shadowgraph of the patient. It presents the same image, but amplified in brightness by a factor of 200 times. The heart of the new device is a large electronic image tube.

#### Why Is Amplification Necessary?

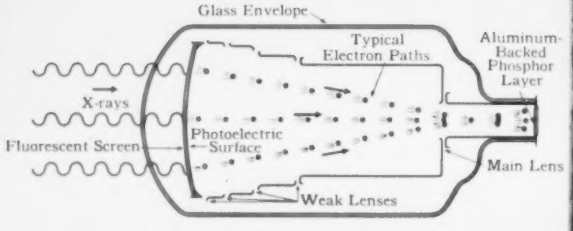
Since their discovery by Roentgen in 1895, x-rays have provided a powerful diagnostic tool for observing the interior of the human body without surgery. The physician can use either radiography—registration on film—or fluoroscopy, whereby the image is viewed on a fluorescent screen. Radiography yields a permanent photographic record, and is the best by far when resolution of fine detail is important. But fluoroscopy reveals information otherwise unobtainable. The doctor can continuously reorient the patient and move or compress the body organs to present the most revealing aspect. As the gastro-intestinal tract flexes rhythmically in its digestive motions, cancerous tumors are seen as interruptions in the normal wall patterns. Fluoroscopy is invaluable to the physician for such things as setting a complicated bone fracture or removing an open safety pin from the lung; to attempt to follow such operations by successive radiographs would be almost as clumsy as trying to drive an automobile using only successive photographs for observing the street scene. But despite their value, fluoroscopes leave much to be desired.

The most serious drawback of the usual fluoroscopic image is its incredibly low brightness. Although the image of a hand is fairly bright, the brightness decreases (roughly exponentially) with thickness. For example, when the full thickness of the patient's abdomen is interposed in the x-ray beam, the brightness is so low that the fluoroscopic image cannot even be seen without several minutes of dark adaptation. The brightness is below ordinary reading level by a factor of $10^{-4}$ to $10^{-6}$. In the worst cases the brightness is about that of a sidewalk at night seen only by starlight, with no moon in the sky. Yet from these tenuous images the doctor must often make life-or-death decisions in behalf of the patient. The limitation is not in the capacity to produce intense x-ray beams, but in radiation hazard to the patient. Greater clarity of image cannot be obtained by increasing the strength of the x-ray beam. This is easily possible technically but it would

**Some of the many development models of the image amplifier tube that were studied in achieving the end result.**

←

**A simplified drawing of the electronic fluoroscope tube. X-rays that have passed through the patient strike the input fluorescent screen. The light from this screen causes electrons to be emitted from the adjacent photoelectric surface. These electrons are focused by a series of lenses before striking the phosphor-coated screen, where they are converted to a visible image, which is then optically magnified.**



endanger the patient in the relatively long time necessary for the usual fluoroscopic examination.

**The New System**

The heart of the new device is the large image tube (see drawing). X-rays pass through the patient and strike the input fluorescent screen, which is basically similar to a conventional fluoroscopic screen. Over this input screen has been deposited a photosurface. Light from the screen releases photoelectrons from the photosurface. Thus the image is made electronic, ready for electronic amplification. True amplification is accomplished by accelerating the photoelectrons through a 30-kv potential difference. The electrons strike a second output fluorescent screen hard enough to release more light than was released from the input screen. The output image with its increased brightness is viewed through an appropriate light-optical system of lenses and mirrors, which properly inverts and reorients the image for optimum viewing.

By present manufacturing specifications the total brightness amplification of the x-ray image tube is 200. About 10 of this is obtained by voltage acceleration; the remaining amplification factor of 20 is ingeniously accomplished by geometrical size reduction of the image. An electrostatic electron-optical system is used to form an inverted output image that is reduced in size relative to the input image by a factor of about 4.5 diameter-wise, or 20 area-wise. Thus the brightness, or emerging light flux per area, is increased by a factor of 20. This 20-fold geometrical enhancement of the brightness is not lost when the image is magnified back to size in the light-optical system that follows. In effect, the eye is brought very close to the image at the output screen, a lens being introduced to accommodate the focus of the eye.

The main electron-optical lens of the image tube is an eighth-inch gap between electrodes, across which most of the 30-kv potential difference is applied. A partially satisfactory image can be obtained when only this main lens is used, but the image is good only at the center. The system of weak auxiliary electron lenses, which accounts for much of the most obvious physical appearance of the tube, serves only to correct the image for good resolution over its full diameter.

The output electron phosphor screen is aluminum-backed to increase the forward light yield, to prevent feedback of light, which would spoil contrast of the image, and to protect the phosphor from chemical attack by the cesium used to sensitize the photosurface.

**The Results**

When this system was first conceived, a brightness intensification of 500 was suggested as the reasonable practical limit. Actually this amplification has been exceeded in some tubes under some conditions. Also because the brightness standard has been changed since the early work, the present specified amplification of 200 would actually be closer to 300 under the original conditions. The remaining difference between the initial estimate and the present result represents an effort to be conservative. As development and manufacturing techniques improve, it may be possible to raise the specifications.

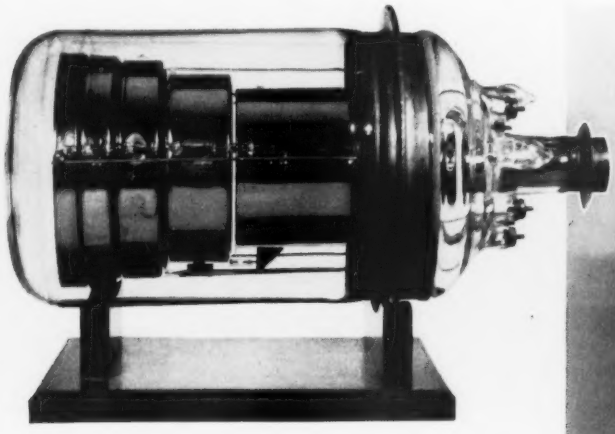
A surprising fact about the electronic fluoroscope is that, despite the tremendous amplification, there is no blinding sensation. In fact, visual estimates as to the magnification are often quite low. The reason lies in the human eye's amazing power of accommodation.

The image amplifier can be viewed in a softly illuminated room by observers without dark adaptation. Under these conditions the conventional fluoroscope is useless for examination of thick body sections, if its image can be seen at all.

By now, the electronic fluoroscope has been tested in a long series of clinical evaluations by outstanding radiologists, with modifications introduced where necessary and practical.

The electronic fluoroscope was first used in an operation in September, 1950, when a girl was flown from Holland to Philadelphia for non-surgical removal of a pin from her lung. Later that same year another doctor observed a larynx cancer with the new device, an impossible feat at the low intensities of the conventional fluoroscope. Although neither of these events was of great medical significance, because satisfactory alternative procedures are available, they do suggest the possibilities of the electronic fluoroscope.

The electronic fluoroscope will become available as the Fluorex in mid-1953. The experience gained will undoubtedly suggest new techniques in x-ray diagnosis, and in utilization of the device itself. All the evidence so far points to the fact that electronics has made a dramatic and valuable contribution to the art it originated, x-ray diagnosis.



**The electronic fluoroscope (Fluorex) in action. Note that a doctor is easily able to manipulate the patient while operating the fluoroscope.**

# *Motocylinder* for Reciprocating-Motion Applications

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**Most of the jobs industry has for powered devices call for rotating motion. But not all. For supplying short linear motion, today's favorite prime movers, turbines and motors, have been at a disadvantage. For these the steam or the air cylinder, for all its inefficiency, is a natural. But the electric motor won't be denied even for this class of service. The Motocylinder, developed primarily for the wood industry, offers a highly attractive means of providing these short linear motions.**

WHEREVER reciprocating motion is required in wood-processing plants, steam cylinders have long been standard equipment. Each steam cylinder consists of a chamber containing a piston, piston rod, and necessary valves. Manual operation of the valve admits steam behind the piston, forcing the piston rod out of the cylinder. The rod remains in this position until the valve is operated again, causing the piston to return. Cylinders as large as 16 inches in diameter with 36-inch stroke are not uncommon. Steam cylinders can exert a large thrust for their size and cost, but are very wasteful of steam. This waste has been unimportant in the lumber industry in the past because there always has been a large quantity of wood waste available for fuel. In recent years, however, this "waste" has been reclaimed for more productive uses; thus the principal advantage of using steam cylinders is rapidly disappearing.

Where steam is not available, some lumber mills are now using compressed air in their cylinders. However, even the air cylinder has the disadvantage of large leakage losses and high maintenance and, of course, compressed air itself is expensive. The inherent disadvantages of steam or air cylinders are rapidly assuming greater economic importance, thus creating the need for a more efficient replacement. The Motocylinder, an electrical machine[1] that provides a reciprocating motion, now fills this need.

The Motocylinder consists of a high-torque, high-slip gear-motor mounted on a special structural steel base, with a short rugged crank mounted on its output shaft. Cams and limit switches associated with the crank are usually set to stop the crank pin at the 6 and 12 o'clock positions, but can be set for any intermediate position.

Motocylinders have been successfully applied to a wide variety of thrust-motion applications in the lumber industry. Several applications are shown in Fig. 1. For applications requiring motors up to 20 horsepower, gear-motors are used, usual output speeds being 22 or 41 revolutions per minute. A 20-hp unit can deliver an 11 000-pound thrust through a 12-inch stroke in less than a second. Larger units consist of a

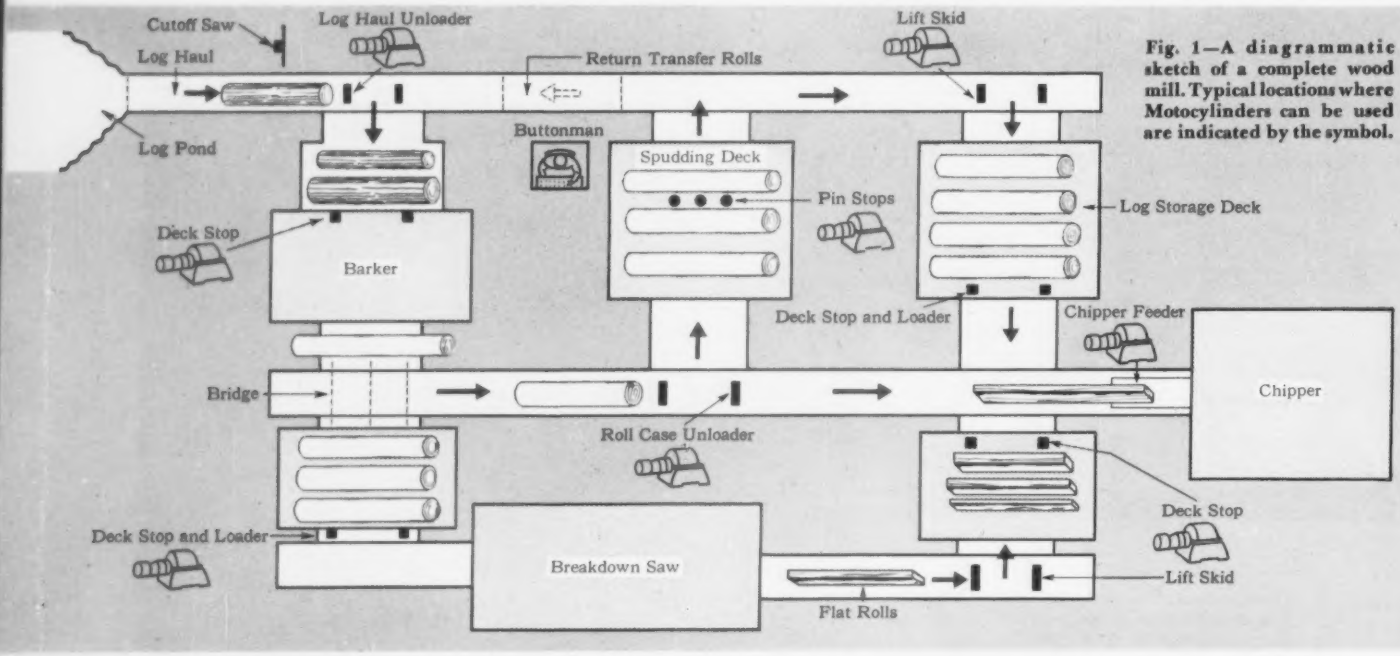



**Fig. 1—A diagrammatic sketch of a complete wood mill. Typical locations where Motocylinders can be used are indicated by the symbol.**

separate motor coupled to a gear reducer, with the crank set apart and driven by a chain. This arrangement is known as an "offset" Motocylinder. Offset Motocylinders are built in ratings up to 50 hp.

The Motocylinder is connected by a crank arm to the device to be pushed, pulled, or lifted. The control is normally arranged so that operation of a foot switch or pushbutton causes the Motocylinder to operate in half-revolution steps. After each half revolution of the crank, a limit switch stops the motor. The crank remains in this position until the operator releases the pushbutton, causing the Motocylinder to make a second half revolution back to its original position and stop. A typical Motocylinder application—loading and unloading logs for a debarking operation—is shown in Fig. 2.

The Motocylinder must have high starting torque (about 300 percent of full-load value) since it must start and rapidly accelerate heavy loads. Between each start and stop the motor makes only about 13 revolutions and can be started as frequently as 30 times per minute. The high-torque, high-slip motor used in the Motocylinder has proved itself adequate for this severe service.

An oversized disc-type brake is used because of the frequency with which the unit is started and stopped. Because the disc brake adds less inertia to the system for a given braking torque than other brakes, its use makes faster acceleration and braking possible.

Unusually rugged gear cases and gears are used because of the severe service encountered. A short, low-speed shaft permits the crank to be located close to the gear case. This reduces overhung loading on the gearmotor bearings and is a major part of the Motocylinder design.

Since most Motocylinders are installed on wooden floors they are provided with a wide-spreading structural-steel subbase. This gives the unit additional height to allow maximum crank throw and also provides the increased mounting surface and provision for the additional mounting bolts required for satisfactory installation on a wood floor.

The Motocylinder is being used more and more frequently in the lumber industry due to the advantages it enjoys over the cylinder and piston devices. Maintenance is greatly reduced. Only occasional lubrication and brake adjustment are required. In contrast, steam- or air-cylinder maintenance calls for frequent adjustment or replacement of piston rings and glands, and the electrically operated solenoid valves used to control steam flow. While the first cost of Motocylinders is higher than for cylinder and piston devices, the overall installation cost of a mill can sometimes be reduced by their use, because long runs of steam or air lines and water drain lines are eliminated and boilers or air compressors can be reduced considerably in size.

The energy required for operation of a Motocylinder is extremely low. This is because the unit, including its electric brake, is energized only during its operating period. There are no standby or leakage losses such as those existing with steam or air cylinders.

A continuing increase in the use of the Motocylinder is probable. There will be less and less really "waste" fuel available in wood mills, and other industries will find the use of the Motocylinder attractive as they become familiar with its advantages.

[1]The Motocylinder was patented as an "Electric Lifting Device" by F. W. Horstkotte, December 8, 1942.

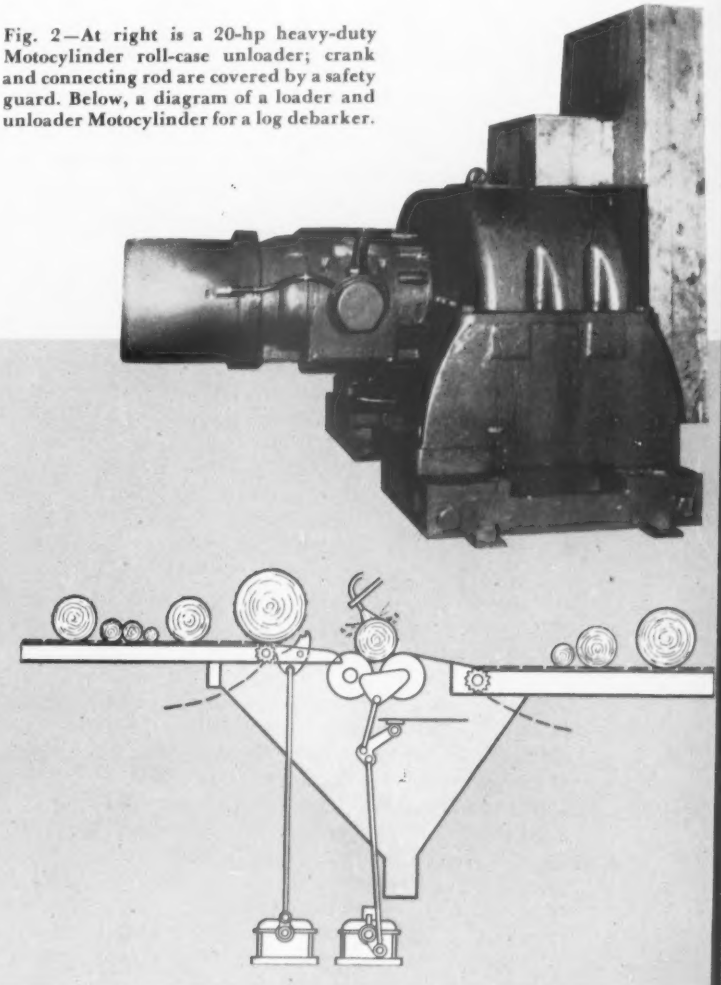
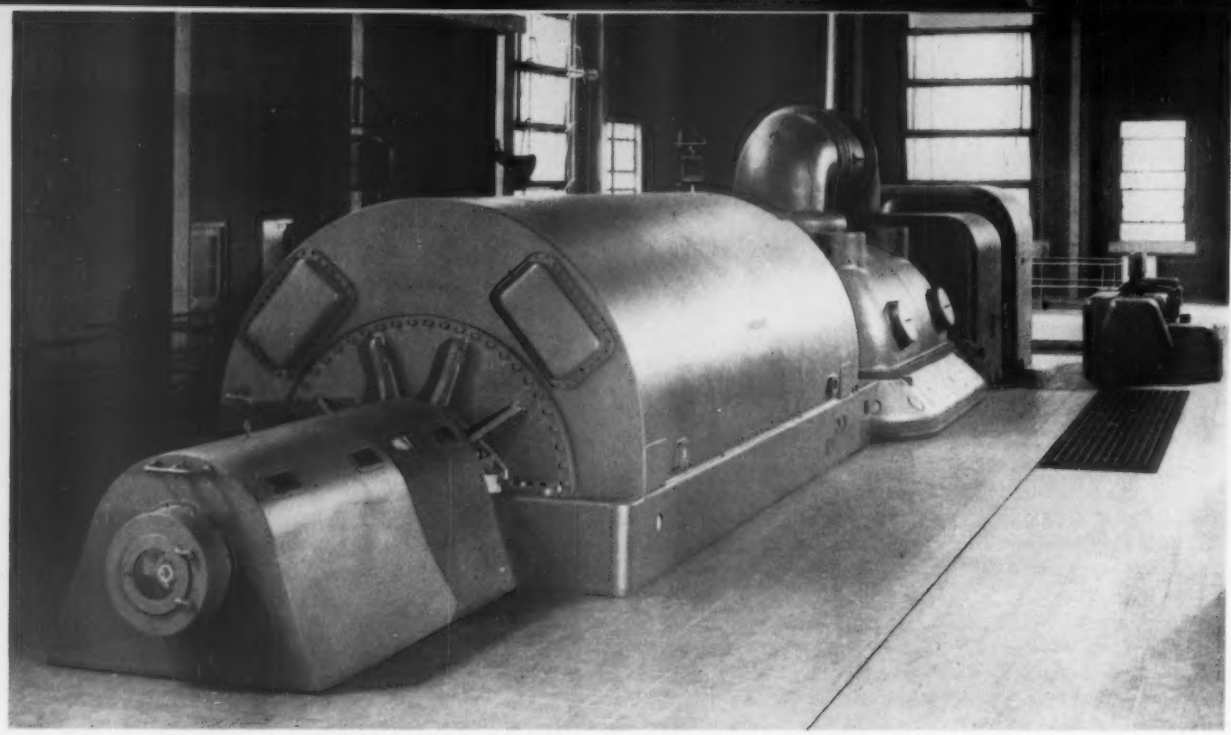


**Fig. 2—At right is a 20-hp heavy-duty Motocylinder roll-case unloader; crank and connecting rod are covered by a safety guard. Below, a diagram of a loader and unloader Motocylinder for a log debarker.**

**TABLE I—TYPICAL MOTOCYLINDER DATA FOR SAWMILLS AND WOOD MILLS**

| Motocylinder Application | Typical Stroke Time—Seconds* | Typical Stroke Length—Inches† | Typical Range of Horsepower Ratings |
|---|---|---|---|
| Log-haul unloader (heavy duty) | 0.75–1.0 | 18 | 15–50 |
| Log-haul unloader (moderate duty) | 0.75–1.0 | 18 | 10–25 |
| Roll-case unloaders (general purpose) | 0.75–1.0 | 18 | 7.5–20 |
| Log kickers (heavy duty) | 0.75–1.0 | 34 | 20–50 |
| Log kickers (moderate duty) | 0.75–1.0 | 34 | 10–20 |
| Deck stop and loaders | 0.5–1.0 | 90-degree rotation | 7.5–20 |
| Pin stops | 0.5–1.0 | 18 | 3–7.5 |
| Lift skids | 0.5–1.5 | 18 | 3–7.5 |
| Skid lifts | 0.5–1.5 | 18 | 3–7.5 |
| Lumber sweeps ("Swedes") | 0.5–0.75 | 14 | 3–5 |
| Lumber stops | 0.5–0.75 | 8 | 1–3 |
| Cant unloaders | 0.5–0.75 | 12 | 5–15 |
| Barker loader | 0.5–1.0 | 24 | 7.5–20 |
| Barker unloader | 0.75–1.5 | 48 | 15–75 |
| Chipper loader | 1.5–3.0 | 26 | 7.5–15 |
| Cutoff saw | Variable | 60 | 0.3–10 |
| Log-carriage loader | 0.5–1.0 | 90-degree rotation | 7.5–15 |

*Stroke time faster than 0.75 second should be avoided unless necessary to meet operational requirements. Those faster than 0.5 second are generally impractical.
†Values given are subject to considerable variation depending on layout of the specific mechanism.



**Typical of hydrogen-cooled turbine generators is this 75 000-kw unit; it can be operated over a range from 0.5 to 30 psig pressure.**

# *Hydrogen Cooling* for Turbine Generators

**A simple physical fact makes possible greater output from a given generator. The fact: a gas becomes more dense as its pressure is increased, and the more dense it becomes the greater its ability to absorb heat. This makes hydrogen cooling of generators extremely attractive, especially at higher gas pressures.**

J. W. Batchelor, *Generator Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

The introduction of hydrogen as a cooling medium for turbine generators about 1926 provided a means for designing machines capable of greater loads for the same amount of material than was previously possible with air cooling. Early generators were designed for operation with a hydrogen pressure of 0.5 psig. Since output capacity increases with hydrogen pressure, it was not long before additional capability was made available by providing for operation with hydrogen pressures up to 15 psig. While permissible loading is not a straight-line function of gas pressure, to simplify operating procedure the usual practice is to allow one percent increase in load per one psig increase in pressure for the range up to 15 psig, and two-thirds percent per one psig from 15 to 30 psig. Since about 1940, many machines have been operated at 15 psig, and a few at pressures up to 30 psig. Because of diminishing returns, further increases in operating pressure on conventional machines are not worthwhile.

However, changes in fundamental generator design will make still higher hydrogen pressures desirable so that the attendant savings in material, space, construction costs, and manpower can be realized fully. No generator-design changes have been required in raising pressures to the present operating point of 30 psig, since the original design of the 0.5-psig machines anticipated these higher pressures. In fact, the only changes required for 30 psig have been in the indicating equipment, such as gauges and manometers. Obviously, a major design change such as that incorporated in inner-cooling* entails many other factors, and changes the hydrogen-cooling picture considerably. These specific problems are not included here, but will be incorporated in a later article in this publication.

### Effect of Gas Pressure on Cooling

The effect of increasing hydrogen pressure is to increase the density of the gas and thus its capacity to absorb heat. Also, the surface heat-transfer rate is improved materially, although not as much as the increase in ability of the hydrogen to absorb heat.

The temperature rise of the stator and rotor windings, in general, is made up of four components; the thermal drop (i.e., heat flow) through the insulation, the drop through the iron, the drop at the surface, and the temperature rise of the gas. Of these, at 0.5-psig hydrogen pressure, the drop through the insulation is the largest, the gas rise the next largest, and the surface drop the smallest. The thermal drops through the in-

*Announced by Westinghouse in November, 1951, inner-cooled generators have hollow rotor and stator conductors through which the cooling gas passes. Since the hydrogen gas is in intimate contact with the copper, the increased cooling effect makes possible much greater output from a machine of a given physical size, or, conversely, a machine of the same output requires less material and is therefore smaller and lighter.

sulation and iron are independent of pressure. The surface drop actually decreases slightly with increasing pressure, but since the value is a small proportion of the total, for the purpose of this analysis it can be considered negligible. Obviously, then, the gas temperature rise has a marked effect on the temperature rise of the generator windings at low gas pressures, but the effect diminishes as the gas pressure (and hence density and heat-absorbing capacity) is increased. It is this gas-temperature rise, however, that can be operated upon to obtain additional capacity and more effective use of the active material.

Consider first the stator coils. The temperature distribution axially along the coils is unequal, because, for one thing, the insulated end turns are exposed to the gas while the center sections are embedded in the stator laminations. Furthermore, the gas temperature near the center of the machine is higher than that at the ends because of the additional heat picked up in reaching those sections. Since gas-temperature rise has a direct effect upon the temperature rise of the stator coils, a reduction in this factor by increasing gas pressure tends to

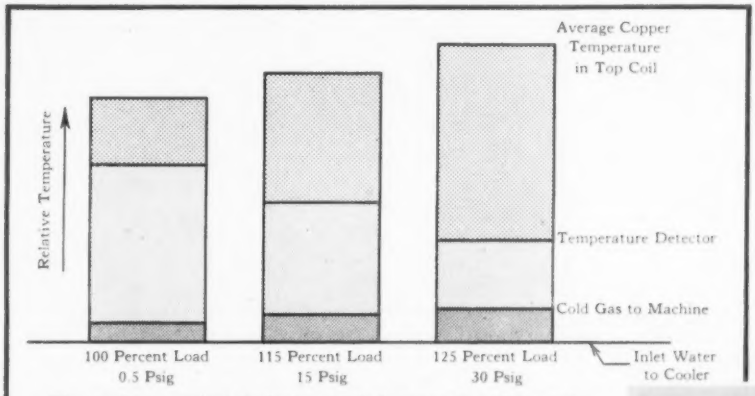

Average Copper Temperature in Top Coil
Relative Temperature
Temperature Detector
Cold Gas to Machine
100 Percent Load 0.5 Psig
115 Percent Load 15 Psig
125 Percent Load 30 Psig
Inlet Water to Cooler

**Fig. 1—In a typical hydrogen-cooled generator of conventional design, some of the various elements that make up the copper temperature rise bear this relationship to each other.**

even out the temperature distribution over the length of the coils, or, conversely, establishes conditions that permit increased current in the coils. For stator-coil insulation insufficiently elastic to allow coil movement caused by thermal expansion under all conditions of operation, higher gas pressure can be used to increase the life of the insulation. This is particularly true when system conditions dictate frequent removal of load. Tests indicate that rate of change of load has no particular bearing on insulation life. The dominant factors are the number and magnitude of the cycles.

Rotor coils differ from stator coils only in that the major portion of the copper in the end sections is exposed directly to the gas, whereas in the stator they are enclosed in insulation. The axial temperature distribution is much the same. Again, by increasing gas pressure, the temperature distribution can be evened out, or the current can be increased.

In the general case, at rated conditions slightly more temperature margin is obtained on the rotor by increasing gas pressure than is the case on the stator (field current doesn't increase as fast as load current). Also, generator power factor is usually higher at overloads than at rated load, hence field current and temperature are reduced. Thus, with the construction used on present rotors, slightly less advantage is gained on the rotor than on the stator by operation at increased hydrogen pressures.

The connecting leads on the stator winding, as well as the main lead bushings and terminal boxes, are exposed to hydrogen, and their current-carrying capabilities are improved with operation at higher gas pressure. This is particularly important for those infrequent cases where bushings are completely enclosed on their outer end so that heat transmitted from the bus is dissipated within the machine.

As system conditions change, increased attention is being given to underexcited machine capabilities. Under such conditions additional losses are generated in the end sections of the core because of leakage flux that enters perpendicular to the flat surface. A magnetic shield at the ends of the core keeps the major portion of this flux out of the laminations. Since ventilation is provided for both sides of this shield, better loss dissipation is obtained at increased gas pressure.

The temperature of the rotor winding is determined by the increase in resistance, and no error is introduced by a change in gas pressure. This is not the case, however, with the temperature detectors in the stator. These detectors, located between coils in the slots, indicate a considerable reduction in stator-coil temperature as gas pressure is increased. On the basis of calculations and tests for a 0.5-psig machine, the present standards of 115-percent load at 15 psig and 125-percent load at 30 psig have been established, using the rule-of-thumb in the opening paragraph, as representing the capabilities of these machines. This allows approximately constant temperature to be maintained on the copper in the stator coil, and the rule should be adhered to in spite of the apparent margin in stator temperatures as indicated by de-

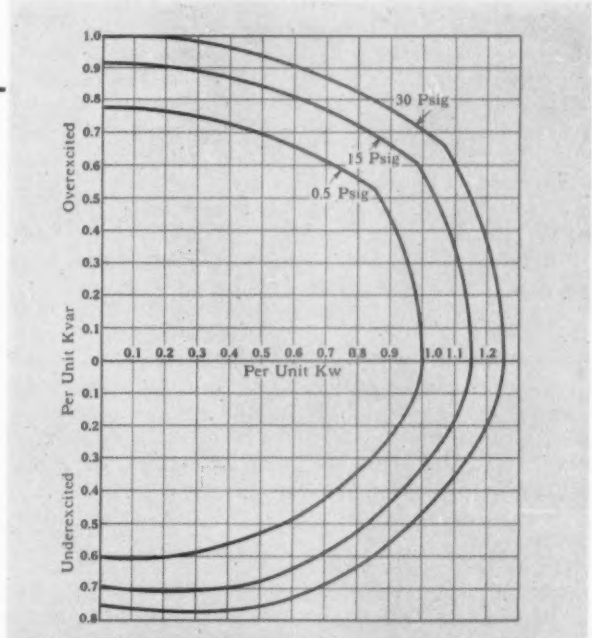



**Fig. 2—These capability curves for a conventional machine operated at different hydrogen pressures are plotted in per unit values. They apply to a wide range of generator ratings.**

tectors. A general rule for detector variation cannot be established for several reasons: gas blowing over the sides of the detector at the vents causes additional cooling; proportions of the machines differ, and nonuniformity of slot size calls for detectors of varying widths; and temperature margins differ between machine designs. Therefore, the ratings as given above should be followed. If temperature limits for the operators are desired, they should be established by test on the individual generator.

When inlet-water temperature is higher than that anticipated in the design, the hydrogen pressure can be increased with consequent reduction of the copper temperature, even though the cooling-gas temperature is increased. The result is greater load capacity.

**Disadvantages**

The disadvantages of higher hydrogen pressures should be considered as well as the advantages.

Because the pressure developed by the blowers and the back pressure of the ventilation circuits in the generator are both proportional to the absolute gas pressure, the rate of gas flow does not change. The windage loss increases directly with absolute pressure. While this loss is relatively small, when coupled with the increased variable losses for the higher capability, a slight reduction in generator efficiency results. Compared to the additional capability of the generator, this reduction hardly requires consideration.

Another minor drawback is the additional hydrogen required. Again, this is not a major factor compared to the increased capability. Any increase in hydrogen consumption is usually traceable to mechanical limitations of existing gaskets and valves and is to be expected.

Cooler size is determined by the design requirements at 0.5 psig. Under this condition, the gas-temperature rise through the generator is a maximum. When the pressure and density are increased, the gas-temperature rise is reduced accordingly. In order that the mean temperature difference be maintained, a corresponding increase in inlet gas temperature must take place. Thus the ambient temperature increases slightly above 40 degrees C, and full advantage of the reduced gas-temperature rise in the generator cannot be obtained because the total temperature of the copper in the windings must be limited to approximately the values attained at 0.5 psig.

The major disadvantage is one directly related to safety. At increased hydrogen pressures, increased leakage should be expected, and a greater possibility exists for hydrogen to collect in pockets in the building or around the machine. This possibility is enhanced by the desire for a "streamlined" appearance, which requires covers over many of the functional parts of the unit. Operation at higher pressures therefore calls for more attention and more careful maintenance. The overall design is being reviewed to improve gas-tight joints and to insure adequate venting. As an added precaution, the surrounding structures should be inspected to determine that the possibilities for the formation of pockets have been reduced to a minimum.

**Summary**

Generators of conventional design can be operated at increased loads with higher gas pressures up to 30 psig, the capabilities thus obtained matching closely the turbine capability. Operation at such pressures brings with it an expected increase in leakage, and consequently a need for more attention and maintenance to safeguard against hydrogen accumulation in the vicinity of the generator.

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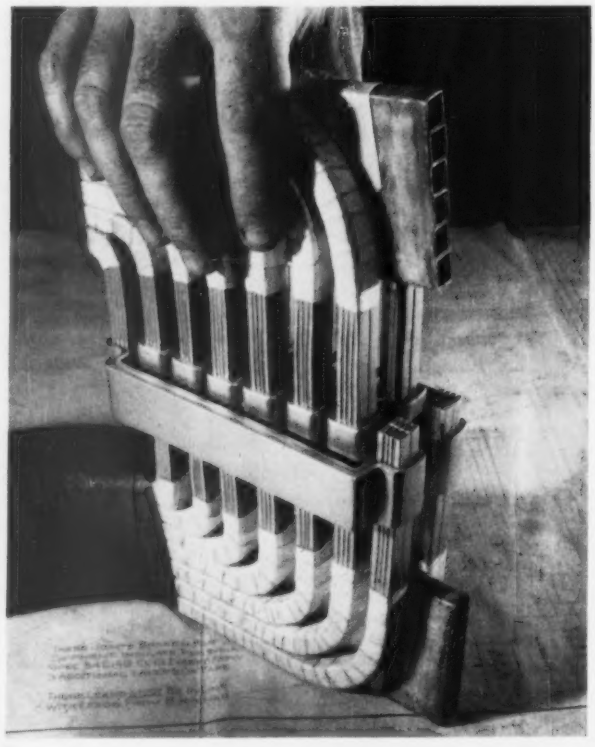
## *Model for Inner-Cooled Coil*

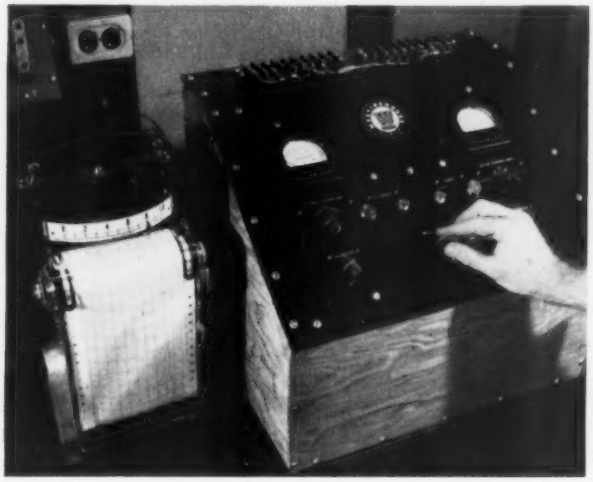
The advent of the radically new method of cooling generators by passing hydrogen through the inside of hollow conductors brought with it a number of coil-design changes. One in particular involves the stator coil ends. Throughout the length of the coil the cooling tubes carrying hydrogen are in intimate contact with the copper conductors, so that maximum heat transfer is obtained. But at coil ends the hollow metal tubes must be electrically insulated from the copper conductors surrounding them. The conductors of the coils are connected to each other in the conventional manner and the tubes must have access to the cooling gas. The opening in the ground wall for entrance of cooling gas to the tubes changes the insulation from a dielectric barrier to a creepage surface at that point. Extensive tests on full-sized model coils (like the one in the photograph below) and service experience in similar creepage surfaces have indicated that fully adequate electrical strength could be obtained over the surfaces involved. In addition, "pants" of a synthetic rubber having high dielectric strength, excellent voltage endurance, nontracking surface, and anti-wetting properties are fitted over the coils and hydrogen tubes where they separate.



# What's NEW! . . . . . in Engineering

## Magnetic Amplifiers Plot Their Own Curves

CURVE plotting has traditionally been a manual operation. Now it, too, is being done automatically. To apply magnetic amplifiers properly, control designers must know the transfer curve of each individual unit. Because of the important functions magnetic amplifiers play in control systems, the transfer characteristic must be maintained within close limits. This has required a test on each production unit, to provide data from which a curve can be drawn. This takes time.



Now the curve is drawn automatically in one minute in a test device (above). The operator places the magnetic amplifier in position and makes the electrical connections. As control or input energy is fed in and automatically increased at a preset rate the output is measured and the two quantities registered as a single curve by a graphic recorder. The trick is to keep motion of the chart paper in step with linear increase in control input (the abscissa of the curve). This is accomplished by a simple feedback-control system regulating the control input current to follow accurately a small signal that is proportional to the linear travel of the chart. The position signal is obtained from a special potentiometer mechanically coupled to the recorder.

## Automatic Rolling of Magnesium

A MILL is being built for the rolling of magnesium from foot-thick slabs down to about 0.2 inch virtually automatically. One operator administers the controls of the main 6000-hp motor driving the reversing mill, the 1500-hp edger motor, the screwdowns, and all other auxiliaries. To make a pass in one direction the operator moves a single handle forward. All of the several adjustments and motor controls are actuated automatically. The pass completed, moving the master switch in the opposite direction causes the new settings to be made according to a preset pattern and the rolling to proceed. Rolling after about 0.2 inch the strip becomes so long that it must be coiled and reheated before each pass. This reheating and rolling process continues until the slab of magnesium has become a long sheet of the desired thickness, between 0.05 and 0.125 inch.

## Simplified Diesel Load Regulator

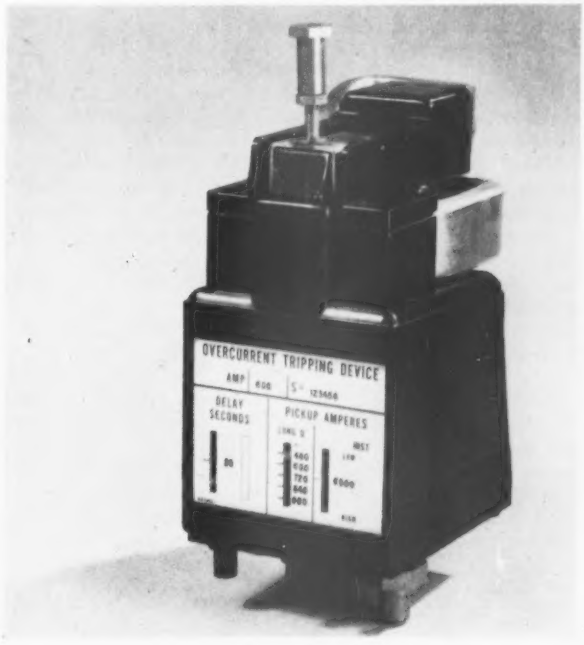
EVOLUTION in railroad diesel load regulators will soon take all of the skill out of dining-car coffee drinking. The smooth starts and stops are getting smoother as a result of continual improvements in the "workings" of the regulator system.

Speed control of the diesel locomotive is accomplished by regulation of the diesel-engine power and the exciter-field voltage. Two years ago, a carbon pile was used in the load regulator to adjust the exciter-field voltage. The principal drawback to this regulator was the lack of definite steps of resistance, or definite maximum and minimum values. A rheostat, made up of tapped resistors connected to a commutator, and jointly controlled by the throttle and the improved load control, now eliminates this disadvantage. When a locomotive unit now works with others, all share the work evenly, both in starting and in dynamic braking.

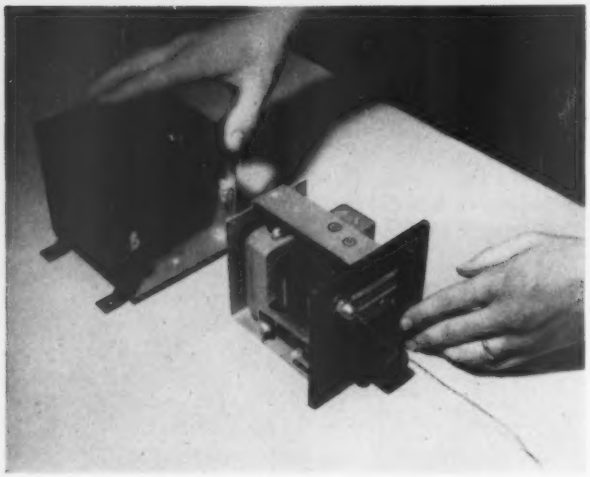
## A Better, Fast Thinker for Motor Breakers

THE CIRCUIT breakers used with a number of motors driving, for example, the many auxiliaries in a powerhouse have a good deal of quick "thinking" to do. On the occasion of a fault each has to decide whether it should open immediately or give another breaker closer to the spot in trouble a chance to act first. Also a breaker must distinguish between a nearby short-circuit and a heavy overload and give the overload a chance to subside before moving in on the situation.

The gadget in the breaker that does the "thinking" is the overcurrent tripping device. A new one (below) is considerably improved in many ways. The timing device, by which its tripping action is coordinated with other breakers, now consists of an air chamber with an external adjustment. The previous one has been a good performer but comprised a heavy fluid permanently sealed in a chamber with no way to adjust it either in the factory or at the motor. One very precisely made valve—the heart of the de-



vice—takes the place of two. The overcurrent trip is housed in a Micarta case, which provides ample insulation between coil and exposed parts. The magnetic air gap consists of a novel, matched arrangement, that produces the optimum in force-travel characteristics needed to deliver the maximum tripping force for a given size and weight.



**Window-Heating Regulator—A new regulator for deicing of airplane windows is made much less subject to changes in humidity. The very sensitive portions of electronic control are hermetically sealed in inert gas. The entire unit is supported on shock-absorbing mounts and functions normally throughout a temperature range from —65 degrees C to +71 degrees C, and does not change calibration when subjected to humidity or moisture condensation.**

## How to Keep from Blowing Your Stack

LIGHTNING reacts to a towering industrial smokestack much like a bull to a red flag. Because these stacks are usually the highest structure around, lightning charges full steam at them. If the stacks are well protected, all is well; if not—you literally pick up the pieces.

Recently an industrial firm wanted to try a new system of protection, but first they naturally wanted to know if the idea was sound. Westinghouse engineers provided the answer.

The problem of protection has a standard solution as outlined in the Bureau of Standards Handbook—two external down conductors on opposite sides of the stack, connected between air terminals at the top of the stack and ground? Supplementing this in reinforced concrete stacks, the reinforcing metal is electrically interconnected, and joined to the down rods at the top and bottom.

The question was—could the external conductors be eliminated and depend solely on embedded conductors (either the reinforcing steel or a separate conductor) electrically connected to the air terminals at the top of the stack and grounded at the base? Would the high currents of the lightning bolt blow the stack apart? Results show that they will not—if the internal electrical connections are solid.

To demonstrate this, engineers constructed a concrete cylinder, 18 inches long and 4 inches in diameter, in which small conductors were embedded. Conductors were two types, bare and cotton braided. The latter was used so that it might be saturated with water to simulate the condition where the down conductor and the concrete did not make a close bond, and the rain seeped down between wire and concrete. Under such conditions it was conceivable that the heat of the wire would turn the water to steam and damage the stack by pressure.

The "stack" represented by the concrete cylinder was then tested under a variety of conditions, with currents from 164 000 to 200 000 amperes. The result of this test—no damage.

To compensate for the shortness of the cylinder a 3.5 microhenry inductance coil was connected in series with the cylinder, between it and ground. This is the equivalent of about nine feet of conductor, not the equal of a high smokestack, but similar to a concrete foundation for a lightning arrester. To intensify the possibility of streamer currents from conductor through the concrete to space, a grounded wall was located near the test piece. No effect on the concrete at high currents was observed.

To simulate cracks in the concrete a special cylinder was made with a number of fine radial holes from the conductor out to the surface of the concrete cylinder. Several grounded copper bands were wrapped directly over the holes and the 3.5 microhenry inductance coil was connected in series with the cylinder. A surge current of 164 000 amperes ruptured the cylinder at the location of the bands, due to the destructive effect of the current jumping from conductor to band. This illustrates the case where external down leads are used jointly with internal reinforcing metal, where the two are not joined electrically at the top, but only at the bottom. The tests show that, if external down leads and reinforcing metal are used in conjunction, they must be joined top and bottom. They also show the destructive effect of lightning currents at joints of embedded conductors that are not electrically connected.

The lesson learned: as long as embedded conductors are solidly connected, the scheme is sound; an open or poorly conducting joint would be catastrophic. In short, the scheme of using only embedded conductors (either the reinforcing metal or separate conductors) is successful as long as electrical connections are solid. The usual aerial terminals and a solid ground at the base of the stack are, of course, requisite.

## An Alternator without Brushes

WHEN AN aircraft-power-supply engineer indulges in pleasant daydreaming he contemplates the banishment of brushes. In aircraft service, particularly, brushes are troublesome.

Designers of aircraft alternators have produced one solution to the problem of brushless alternators that is commanding respect. Two ratings of brushless alternators have been built, one for 11 kva, another for 60. The alternator itself is essentially standard. The trick is in the excitation supply. On the shaft with the alternator is a rotating armature a-c exciter, the output of which is fed to a bank of selenium rectifiers rotating with it (see photograph). The rectifiers deliver direct current to the alternator field.

Preliminary tests are gratifying. The 11-kva machine, which normally would run at 4000 to 8000 rpm, has operated on an overspeed of 11 000 rpm with no apparent distress to the rectifiers or other elements. The experimental 60-kva machine was built

into the frame of a standard 60-kva alternator with space to spare. It has carried 150-percent load for 5 minutes and has survived short circuits of 200 percent for 5 seconds, and 300 percent for 3 seconds. The overall efficiency is slightly better than a standard slip-ring machine, exceeding 90 percent from half load upward. The weight of production models will probably be no more, and possibly less, than for conventional machines.

The usual rate-of-change signal from the excitation circuit used to stabilize the voltage regulator is no longer accessible. An extra coil on the exciter field supplies this anticipating signal very nicely, however. The output of the coil is fed to a regulator coil and gives an anti-hunt signal in just the right phase with respect to the alternator field to damp out the tendency to overshoot and oscillate. Perhaps the alternator designer will make his own favorite dream come true.

## The Short-Arc Mercury Lamp—Boon to Searchlights

SEARCHLIGHTS are being adapted to use the relatively new short-arc mercury lamps with a resulting great increase in beam candlepower, but with no increase in energy consumption. Last year was mentioned the probable application of the 1000-watt short-arc to the 12-inch signaling searchlight used by the U. S. Navy. Last summer this searchlight very successfully passed its sea trials. The lamp develops six-million beam candlepower, which is nine times more than from the same searchlight using an incandescent lamp of the same wattage. With this startling improvement it is likely that many of the searchlights built during the last war will be modified to use the mercury lamp.

The good performance of the 1000-watt short-arc mercury lamp is leading to the development of an experimental searchlight designed to use the very new 5-kw short-arc lamp. This should give a beam output of 30 million candlepower. Thus the Navy will have a compact, lightweight searchlight with a long-sought rating intermediate between the two-million candlepower available with incandescent lamps and the better than 100 million practical with carbon-arc units.

Ordinarily a searchlight beam, in cross section, is round. But for the Coast Guard a flat beam is best for searching, say, objects on the water or on ice. With the 1000-watt short-arc lamp and a new mirror, a searchlight produces a beam that is two degrees thick vertically and eight degrees long horizontally. By comparison with the previous searchlight using a 1000-watt filament lamp, which produced a two-million candlepower beam in a 1½-degree circle, this new one averages two million over an elliptical area about ten times larger. This beam is obtained by a special mirror that is elliptical along one axis, parabolic along the other.

A new method of making metal mirrors for searchlights is under development. This is to form the mirror by pressing the metal blank into an almost true parabola and finishing the job to high precision by grinding. Mirrors have been made by building up the metal surface by electroplating onto a layer of graphite painted on a glass mold, or by cutting the parabola into metal using a tracer control from a pattern. The new method should produce a mirror that is both better and cheaper.

# . . . . . in Products

## Sudden-Pressure Relay for Power Transformers

THE NUMBER of bodyguards assigned to a public figure is sometimes used as a measure of importance. Using this criterion, the power transformer is indeed a figure of considerable stature. It has "bodyguards," in the form of protective devices, for nearly every eventuality. Yet new schemes and methods continue to appear, and the transformer "hires" them. And for good reason. Power outages on any size transformer are a nightmare for utility engineers, but the larger the transformer, the worse the problems become. Plus the fact that a power transformer may represent an investment of perhaps a half million dollars or more. A new sudden-pressure relay is one example of the kind of protection given the modern transformer.

Heavy faults in a transformer require quick detection, and equally quick action. This new relay (called the SPR) is designed to give both. A fault breaks down a certain amount of the transformer oil, resulting in the evolution of gas. The sudden-pressure relay operates on the sudden change in pressure brought about by the release of this gas.

Most transformers have absolute-pressure relief diaphragms that act when internal pressures build up to an unsafe amount; however, the new relay, since it acts on any uncommon *rate* of change, goes into action long before the relief valve can act. The two safety devices thus supplement each other—one operating on sudden changes, the other on prolonged overload.

Basically, the device consists of a small bellows, and a single-pole, double-throw microswitch. The operation of the relay is governed by an equalizer, a small pipe plug with a small hole that forms an opening between the transformer gas space and the relay case. This opening "throttles" any pressure difference between the case and the gas space, and causes the bellows to operate the microswitch. This pressure differential of only a fraction of a pound per square inch initiates the action, either giving an alarm or removing the transformer from service.

The new sudden-pressure relay has several notable advantages: it operates on sudden increases in gas pressure, regardless of the operating pressure of the transformer; it will operate on a rate of rise in pressure as low as 0.071 pound (1.1 ounces) per square inch per second; at high rates of increase—10 to 15 pounds per square inch per second—it operates in two or three cycles; it does not operate on those changes in pressure common to transformer operation.

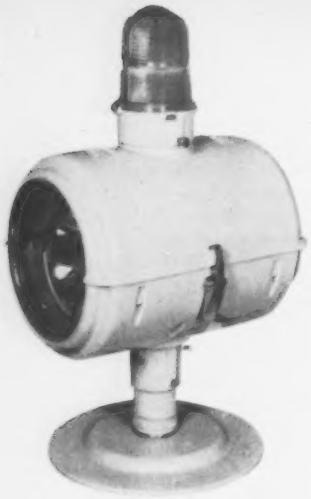
Thus to the already impressive array of transformer bodyguards is added a new device—one that performs a valuable new function in transformer protection.

*An advance power-generation unit for use in devastated areas, will utilize a 5000-kw gas-turbine power plant. This unit, to be built for the U. S. Army's Corps of Engineers, will be mounted on two railway cars. The generator car will contain the 5700-rpm gas turbine, which will be designed to burn diesel oil; a geared speed reducer to enable the generator to operate on one of two speeds (3600 rpm for 60-cycle power, or 3000 rpm for 50-cycle power); a 2400-volt generator and its exciter; and the starting motor for the gas turbine. The transformer-control car will contain a multi-voltage transformer, with output from 2400 to 15 000 volts; high- and low-voltage switchgear; two diesel generators for auxiliary power.*

## Beating the Fog

THAT double row of airport runway lights that looms up out of the darkness in a nighttime landing is as vitally important and reassuring to the pilot as it is symmetrically attractive to the passenger. These lights, spaced about 200 feet apart along both sides of the runway, are a clear indication of the runway outline; it is important that they be visible even during fog or bad weather. A newly designed high-intensity light assures that the indication will be there even when visibility is restricted to one-eighth mile, instead of the half mile of the previous unit.

The new runway light casts a beam along the glide path of 170 000 candlepower; the previous unit, 110 000. This increase is obtained with substantially the same lamp wattage and no change in the lamp circuit or its auxiliaries. The only change is in the lamp (PAR 56) itself and in its holder. To obtain a brighter, more concentrated light source, the filament size was reduced (at a sacrifice in life), the reflector diameter was increased



and the focal length was changed.

Several improved mechanical features have also been incorporated in the new unit, making it simpler to install and maintain. Leveling is accomplished by turning four screws in the adjuster plate, instead of by the previous ball and socket arrangement. The unit is easily opened by manipulating one latch. The top lens element can be removed (for replacing bulbs) by loosening one thumbscrew. A new casting design has effected a weight reduction of about 15 percent, which reduces the chances of damage in the event it is struck by aircraft.

## Transductor Magnetic Amplifiers Measure High Direct Currents

ENGINEERS working with high d-c voltages and currents have long cast envious glances at the simple and compact instrument transformers available to the a-c engineer. A new version of an old device—called a magnetic-amplifier transductor—is functionally very similar; it is small, lightweight, and offers the safety of metering circuit isolation.

Compactness and isolation of metering circuits previously have been incompatible. The methods of measuring high currents, for example, have involved either a meter connected across a large shunt in the line, which offers no isolation of metering circuit; or the use of a bulky transductor, which often measures several feet in each dimension. In the latter case the main bus serves as the primary of a saturable reactor, the secondary being built around the bus. Alternating current is circulated in the secondary. Changes in direct current in the bus alter the flux produced, thus affecting the saturation of the a-c secondary and its reactance. The small alternating current in the secondary is thus a measure of the large direct current in the bus.

Recent developments in the field of materials—notably magnetic core materials such as Hipernik V—have enabled the construction of small, compact magnetic amplifiers; the new transductor is one version. As mentioned, it is applied in much the same manner as an instrument transformer on alternating current. For measuring currents, it is connected across a small line shunt. Direct current thus circulates in the primary of the magnetic amplifier, creating a flux that alters the alternating current in the secondary; and this alternating current is a direct measure of the main direct current. For measuring voltages, the primary is connected across the line, in series with a resistor. And again, the secondary voltage is a reflection of the main line voltage. In both cases the metering circuit is completely isolated from the main circuit, thus affording far greater safety.

An interesting application of the new transductor is in a chemical plant's "pot" line. Here large amounts of current are rectified in smaller increments by ignitron rectifiers, such that a current of, say, 120 000 amperes, is supplied by 20 ignitron rectifiers, each furnishing 6000 amperes. In this case a magnetic-amplifier transductor is placed across a small shunt in each of the 6000-ampere lines. These transductors can then be easily interconnected such that they total the current and present it to a meter or recording device. Thus the need for large, expensive shunts is eliminated, and, instead, a small, readily available shunt is substituted.

A second method of measuring current eliminates the shunt entirely, at a very slight drop in accuracy. A section of the line, in effect, serves as a shunt. The transductor is connected in parallel with a small portion of the main conductor. A portion of the current-carrying conductor and the length of the magnetic-amplifier control circuit are made equal (three to six feet); thus current divides in proportion to cross-sectional area of wire used. This method is accurate to about $\pm 0.5$ percent compared to the $\pm 0.25$ percent of the above shunt method.

These are but two uses for the new transductor; they are suitable for many industrial, mining, and railway applications where direct current is used. Three standard units of the new magnetic-amplifier transductor are now in production—one unit for voltage and two units for current measurement. The voltage unit is suitable for measuring d-c voltages from 450 to 750 volts. The two current transductors are designed to be used with 50 and 100 millivolt shunts.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## What's NEW!. . . . . Literature

**Industrial-Fan Booklet**

Industrial fans are used for handling everything from air to sawdust, or even long fibrous materials like long shavings from woodworking machinery. The question of "which fan to use where" is not always an easy one to answer. A new booklet (Catalog 1150) entitled "Industrial Fans" describes the construction and operation of each of the different types of fan equipment, and also provides valuable and detailed application information to assist in making the selection for particular uses.

**Lumber-Industry Booklet**

Electricity is fast replacing steam as a power supply in the lumber industry. In some mills nearly all of the lumber processing is done by electrical drives. A new 50-page booklet (B-5299) describes the application of these drives. Components of the various drives are indicated, a typical installation shown, and the engineering application information cited. In addition to the data on drives, the book treats in detail other phases of mill electrification, such as complete lumber handling systems, automatic control systems, air handling, and mill lighting. For quick reference a sawmill drive application chart is included.

**Industrial Turbine-Generator Booklet**

Industrial turbine-generator requirements vary from those in which maximum conversion of heat energy to electrical power is most important to those in which process steam is of primary concern. A new 20-page booklet (B-5418) gives the characteristics of each of the six principal types of industrial turbines, in terms of electrical power and process steam each is capable of delivering. These are the noncondensing, noncondensing single extraction, noncondensing double extraction, condensing single extraction, condensing double extraction, and condensing. The book also includes installation data on representative turbine applications in the textile, metals, paper, petroleum, lumber, chemical, and food industries.

To obtain literature, write to Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh, 30 Pa.

# Personality Profiles

*R. F. Woll's* article on wound-rotor motors in this issue came into being as a result of unfortunate circumstances. Confined by a temporary disability—first in the hospital, then at home, and finally back in his office again—Woll found that time (the thing engineers usually have the least of) was suddenly plentiful. So he forthwith took pencil in hand and turned out many of the articles he had long hoped to do. Among them was the article contained in this issue.

Woll, a native Pittsburgher, is an alumnus of the University of Pittsburgh. He came to Westinghouse in 1937, immediately after graduation, with a B.S. in E.E. He started on the motor-test floor in East Pittsburgh and subsequently was transferred to the Motor Engineering Department. When the whole motor activity was moved to Buffalo in 1946, Woll went along; he is now in the A-C Motor Engineering Section.

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Gentlemen, doff your hats—we have a lady in our midst. The coauthor of the article on Sterilamps, listed rather cryptically as *G. Mouromtseff*, is Miss Gail Mouromtseff, research chemist in the Lamp Research Laboratories. With slightly red faces, we must admit that we sent Miss Mouromtseff the more or less routine inquiry as to her career at Westinghouse, asking for names, places, and—of all things—dates. She graciously and completely fulfilled our request—except for dates, which she just as graciously declined. To a long-standing woman's prerogative, we respectfully acquiesce.

The name Mouromtseff is no stranger to the technical public. Miss Mouromtseff's father, I. E. Mouromtseff, was a Westinghouse pioneer in radio.

Miss Mouromtseff graduated from Pennsylvania College for Women, a major in biology and chemistry. Shortly afterward her father was transferred to the Bloomfield, N. J., plant, and Miss Mouromtseff found a job, as she puts it, "literally dumped in my lap." This was the rare opportunity of working with Dr. H. C. Rentschler, who was looking for a bacteriologist to assist in work on Sterilamps. This work having concluded, Miss Mouromtseff now applies her efforts to research on rare metals.

*Dr. Rudolph Nagy* represents a scientific field seemingly unrelated to the electrical industry—biochemistry. Yet, as Nagy himself expresses it, "As long as we have ultraviolet lamps, we will always have biochemical problems that must be answered, such as the effect of ultraviolet on eyes, skin, various molds, bacteria, and chemical compounds." And, we might add, a great many more.

Nagy graduated from the University of Wisconsin in 1932, then went on to gain his Ph.D. in Biochemistry. Like Miss Mouromtseff he first went to work with Dr. Rentschler on the Sterilamp activity. When the war came Nagy was among those who helped prepare the uranium for the first atomic pile. For the last ten years he has been concerned with research on new fluorescent materials for lamps; his section has also made a sizable investigation into numerous aspects of the phenomenon of electroluminescence.

The third member of the trio of authors of this issue's Sterilamp article is the engineering representative—*F. H. Rixton*. Rixton entered Westinghouse through the Graduate Student Course in 1942, fresh from the campus of Pennsylvania State College, where he had earned a B.S. in Industrial Engineering. His first work was as a manufacturing engineer in the Electronic-Tube Manufacturing Section, an activity then located at the lamp plant. Then, after a brief interlude in the U. S. Navy, he became a part of the vapor-lamp engineering activity. He has assisted in the development of many familiar devices since then, including glow lamps, fluorescent lamp starters, and the "fluorescent Nite Lite." More recently he has acquired the engineering responsibility for many other vapor discharge lamps, including the Sterilamp.

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Much of *J. C. Marshall's* life has been shaped by his love for salt water, boats, and sailing. Marshall was born and brought up in Atlantic City, N. J., and spent much of his boyhood on the Atlantic shores. Coming to Westinghouse in 1940, after graduating from the Electrical Engineering School of Cornell, he spent a year on the Graduate Student Course, then a year in the Pittsburgh Sales Office. During World War II he was loaned to the Navy Department's Bureau of Ships. After the war, Marshall returned to Westinghouse in the Detroit Office.

Probably because Detroit was too far from salt water to suit his seafaring blood, he left Westinghouse in 1946, and with his wife and four-month-old daughter, headed west in search of adventure and the ideal place to live. After a two-month-long trip in a house trailer, they found "home" in San Francisco on the shores of the Pacific Ocean. Shortly afterward Marshall returned to Westinghouse as an application engineer in the San Francisco Office. His list of customers contains many lumber mills, including the only redwood mills in the world.

*D. L. Treder* learned the Westinghouse system of drawings and manufacturing procedures the hard but thorough way—on the drafting board—when he joined Westinghouse at its Emeryville, Calif., plant in 1940. After receiving this worthwhile grounding, he specialized in designing special motor windings and mechanical modifications on motors. During this period he was first exposed to the Motocylinder and its unusual design features.

Treder was transferred to Buffalo when the company opened a plant there in 1946, and worked in the section concerned with small a-c motor development while the Life-Line motor was in its early stages. About a year later he returned to the Pacific Coast and in 1947 went to the newly acquired Sunnyvale, Calif., plant. His present duties include order interpretation for gearmotors, Motocylinders, and standard motors built at Sunnyvale.

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Two of this month's authors hardly need an introduction. One is *E. W. Beggs*, whose articles on various kinds of lamps and lighting have appeared here several times in recent years; and the other is *M. H. Fisher*, who wrote last year on textile-mill problems.

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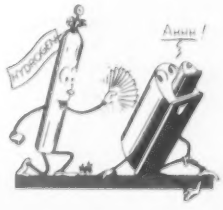
*J. W. Batchelor* is one of those rare combinations of engineer and salesman who, no matter how busy, always has time to talk about generators. He was graduated from Purdue in 1937 with a B.S. in E.E., and immediately joined Westinghouse on the Student Course. He soon became a member of the Generator Engineering Department, and now heads up its Turbine-Generator Section. Not only does he know the job of designing generators, but he has a keen understanding of the problems of their operators.



## Torch Touch-up

This 7-ton core is for an 11-ton turbine-cover casting used at the low-pressure end of a turbine. Made of a black-sand core mixture, the core is supported in the mold by "anchors"; the rests for these anchors are embedded in the core. Here the molder is drying a filling used to cover exposed anchor points.